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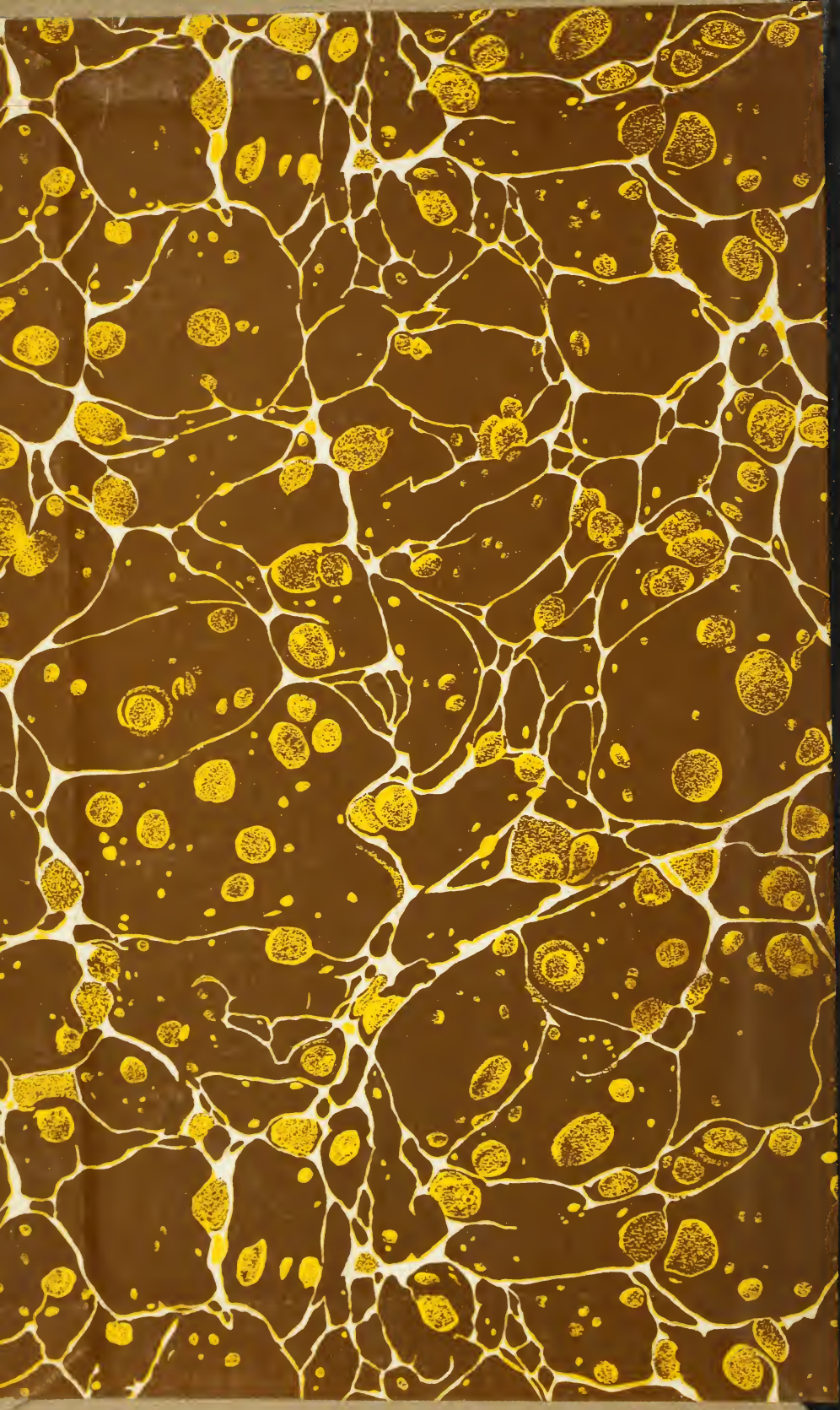

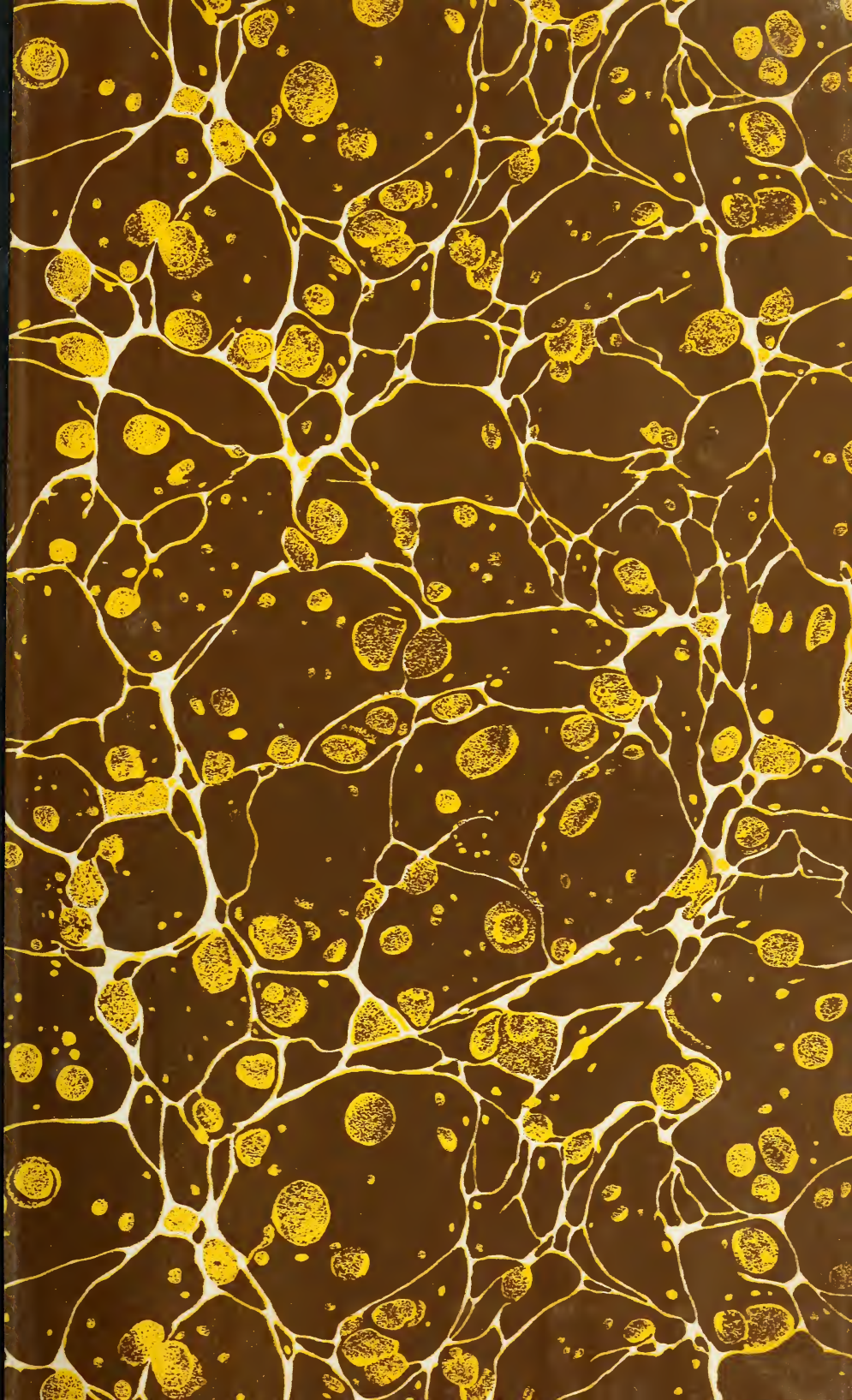

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WASHINGTON, D. C. MARCH, 1930

WEATHER FORECASTING FROM SYNOPTIC CHARTS

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MISCELLANEOUS PUBLICATION NO. 71

Washington, D. C. March, 1930

WEATHER FORECASTING FROM SYNOPTIC CHARTS

By Alfred Judson Henry, *Principal Meteorologist, Weather Bureau*

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INTRODUCTION

The invention of the electric telegraph in the early forties of the nineteenth century made possible the rapid collection of the meteorological data essential to the construction of a weather chart.

In the United States a beginning was made in a very simple and inexpensive way. The late Joseph Henry (1799–1878), director of the Smithsonian Institution, suggested to the division superintendent of telegraph wires entering Washington that data on the state of the weather at the various points reached by the wires could easily be transmitted to Washington when wire tests were made each morning. The suggestion was acted on favorably, and Professor Henry, as a result, was able to display on a large wall map in the Smithsonian Institution from 1854 to 1861 the weather data thus collected. Impressed with the possibilities of the plan, he recommended to the United States Commissioner of Agriculture in 1865

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the establishment of a weather service for the benefit of agriculture, more extensive than that hitherto maintained by the Smithsonian Institution. The Smithsonian Institution was therefore first in this country to illustrate the practicability of constructing a weather map from data collected by telegraph. And it has some show of reason for being referred to as the father of the present Weather Bureau. As a matter of fact, no single individual or institution can justly lay claim to that title. Many persons and organizations contributed to the final result.

In Europe the occurrence of several marine disasters seemed to hasten the day of organized weather services. A very severe storm on the Black Sea on November 14, 1854, caused the loss of nearly 30 naval vessels and their cargoes belonging to the allied forces of England and France. Such a disaster had the effect of starting an inquiry as to the cause of the disaster and the possibility of foretelling the occurrence of similar ones in the future. Le Verrier, of the Paris Observatory, conducted the inquiry, and about a year later was in a position to organize the first international telegraphic weather service. Buys Ballot, professor of physics at the University of Utrecht, Netherlands, soon thereafter organized a forecast and storm-warning service for that country. Admiral FitzRoy, in London, began the collection of daily weather reports by telegraph in 1860 and advocated the organization of a storm-warning service. His plan was put into effect in the early sixties. Thus it appears that while the germ of the idea of a telegraphic weather service had its origin in North America, European countries were first to put the idea into practical operation.

The principal events leading up to the establishment of a Federal weather service in the United States were about as follows: In 1868 the newly appointed director of the Cincinnati observatory, the late Cleveland Abbe (1838–1916), in his inaugural address on May 1 of that year proposed the establishment of a weather service and forecasts for the benefit of the citizens of Cincinnati, and about a year later the Cincinnati Chamber of Commerce inaugurated a system of telegraphic weather reports from which "probabilities" were drawn and distributed to the citizens of that city. This action was largely influential in securing the passage of a joint resolution in Congress in February, 1870, providing for the establishment of a Federal weather service in the War Department.

It has been a source of wonder on the part of many persons that an organization constituted for purely civil duties should have been placed in that department.

The reasons that led the Congress of the United States to assign the weather service specifically to the War Department have not, of course, been given out; yet an analysis of the current thought of the time leads to the conclusion that in the minds of the legislators the belief must have prevailed that the War Department was best fitted to carry out the new legislation. In the first place, the taking of meteorological observations at each military post in the country under the direction of the Surgeon General of the Army had been the practice for at least forty-odd years.

It should be remembered, too, that in 1866 the Army Signal Service, as a part of the Military Establishment, was reorganized. In its reorganized form it consisted of a Chief Signal Officer with the rank

of a colonel of Cavalry, but with no command, although the Secretary of War was given authority to detail both officers and troops from the Regular Establishment sufficient to form a unit around which a signal service might be formed. This anomalous state of affairs continued until 1870. In February of that year the joint resolution of Congress before mentioned was passed, and the Secretary of War assigned the new duty to the Signal Service and approved the plan of expanding the school of instruction at Fort Whipple (now Fort Myer, Va.) so as to include meteorology, and thus the Federal weather service began its duties in the War Department, where it remained until July 1, 1891.

Federal weather forecasters as a class have been criticised adversely for failure to contribute substantially to the literature of the subject. To a considerable extent the criticism is a just one, but the reasons are not far to seek. A tour of duty in a large forecasting unit is not conducive to writing on the subject for publication. Nor do many forecasters gain such mastery of this subject as to feel the urge to write on it.

It should be recalled that on the organization of a Federal weather service in 1870 experienced forecasters were not to be had. The two leading students of meteorology in the United States previous to that time were W. C. Redfield (1798–1857) and J. P. Espy (1785–1860). These two men were distinctly leaders in an effort to discover the nature and explanation of the phenomena of the weather, and, as frequently happens, they did not agree on theoretical grounds. Franklin at a much earlier period had discovered the progressive movement of storms, and this fact seems to have been definitely established in 1753. Loomis, Coffin, and Ferrel had made important contributions to a rational understanding of weather phenomena, but outside of Abbe's work at Cincinnati no attempts had been made to forecast the approach of storms.

The chief signal officer, while primarily interested in building up a strong military organization, had a clear perception of the necessity of bringing to his aid in the new venture civilians of high intellectual attainments, who at the same time were well versed in meteorology. He selected as his first principal civilian assistant, Increase A. Lapham (1811–1875). Lapham was an investigator of some note in the fields of botany, geology, and meteorology and a warm sympathizer with the new service, having been more or less active in urging its creation. He was stationed at Chicago and at Milwaukee, and from the first-named city he issued, on November 8, 1870, the first storm warning for the Great Lakes. He was also responsible for the first official Government weather forecasts, viz, those made in November and December, 1870. Abbe, however, had prepared and issued "weather probabilities" under the auspices of the Cincinnati Chamber of Commerce as early as 1869.

After Lapham had declined a permanent appointment, Cleveland Abbe was called from the Cincinnati observatory on January 3, 1871, and in the same year Thompson B. Maury was given a place on the civilian staff; Abbe, however, doubtless owing to his experience at Cincinnati, led the way in the weather forecasting and the issue of storm warnings. He also had that particular form of genius that enabled him quickly to teach others to equal and even to improve upon his own work as a forecaster. By the middle of 1872 the forecast work of the Signal Service was divided equally between civilian as-

sistants and the group of Army officers who had been detailed for special duty with that service. As time passed, however, the group of Army officers more and more assumed the burden of carrying the forecast and storm-warning service; even as early as 1871 Lieut. Robert Craig shared in the forecast work with Abbe.

Abbe and others were assigned in the early seventies to the investigation of collateral problems, of which there were many, the most pressing being the reduction of barometer readings in the Rocky Mountain and plateau region to sea level. That and other problems were assigned to what was later known as the "study room," presided over by Abbe. To this room was also referred the study of the daily weather map and methods of forecasting. Owing to the multitudinous problems referred to it, its failure to report on the latter may perhaps be overlooked. Later, William Ferrel (1817–1891) was engaged to study specifically the problems of dynamic meteorology, and the study room was thenceforth left to struggle with the more practical questions affecting the conduct of the service.

These remarks are offered in extenuation of the fact that the early weather service made few if any important contributions to the literature of weather forecasting. Greely alone of the commissioned Army officers and H. A. Hazen of the civilian assistants wrote on the subject, and even they wrote very briefly.

Weather Bureau forecasters have not greatly improved on the record of their predecessors. Twenty-five years after the transfer of the meteorological service to the Department of Agriculture and its reorganization as the United States Weather Bureau, a serious effort was made under the direction of C. F. Marvin, present chief of bureau, to assemble in printed form the substance of what was known and practiced by Weather Bureau forecasters. The results were published in 1916 under the title "Weather Forecasting in the United States," by a board consisting of Alfred J. Henry, chairman; Edward H. Bowie, Henry J. Cox, and Harry C. Frankenfield (*9*). The prime object of that work was to aid Weather Bureau employees to fit themselves for the forecast work of the bureau. It was not intended for public distribution, but the demand for it has finally exhausted the entire edition.

This publication, of which the sections on synoptic charts and early forecasting in the United States and abroad are mainly historical, aims to present an account of the methods and practices of weather forecasters so that the average citizen who is interested in such matters may have at his disposal a connected account not only of the material used but also of the manner of its use. It is assumed that many persons have an abiding interest in the scientific work of the Federal Government, without having any desire to become their own forecaster. This publication is distinctly not a handbook of weather forecasting. It is further assumed that no one would be so ill-advised as to attempt to gain skill in weather forecasting without first acquiring a working knowledge of meteorology. Obviously such a knowledge can not be given in a work of this character.

SYNOPTIC CHARTS

Synoptic weather charts may be defined as skeleton maps of the geographical region under consideration on which have been plotted figures and symbols which represent the weather conditions prevail-

ing at a common moment at the various observing stations throughout the region.

A fundamental consideration in all cases is that the numerical data and symbols shall represent weather conditions prevailing at some fixed hour over the entire area.

With the extension of the field of observation to remote parts of the great continental areas this requirement becomes more and more difficult of satisfaction.

THE PRINCIPAL WEATHER CHART

The United States Weather Bureau recently was obliged to provide a suitable chart for the entry of observations from regions that had a range of 180° in longitude and 80° in latitude. A map of North America on a scale of 1:5,000,000, compiled by the United States

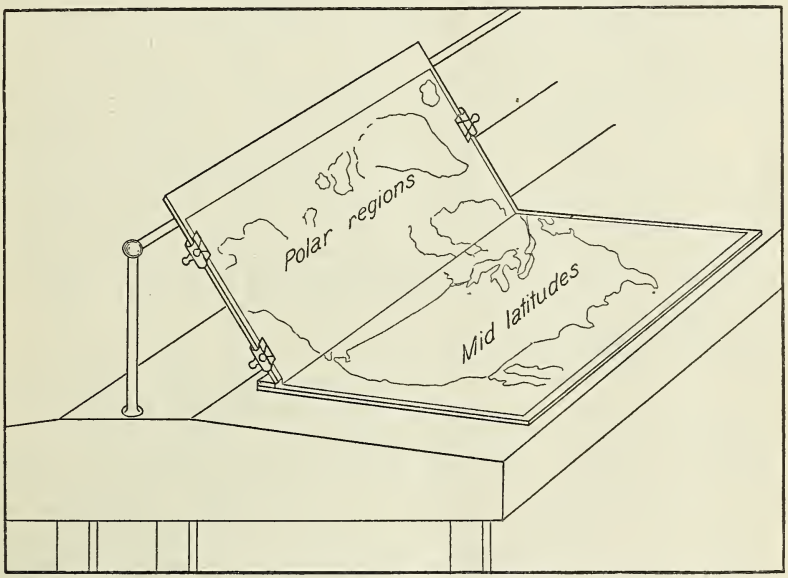


FIGURE 1.—Weather Bureau base map for synoptic charts

Geological Survey was used as a base map. From this map a chart was drawn that substantially filled a sheet of paper 23½ by 27 13/16 inches. By printing the west and east coast lines of North America at the left and right edges of this sheet and the polar area on one side of the sheet and the mid latitudes on the other, the dividing line being in the neighborhood of the fiftieth parallel of north latitude and setting the polar side of the chart in the vertical and in line with the top of the mid-latitude section of a separate sheet at the bottom, as shown in Figure 1, an instantaneous view of the charted weather conditions between zero and 180° of longitude and from 10° north latitude to the Arctic Circle is obtained within a very reasonable and an entirely practicable working space.

It is clear that observational data plotted on this chart are not, strictly speaking, synchronous, there being as much as 12 hours difference in time between the two sides of the chart in the polar

regions. Since, however, the object of the large chart is not so much for use in the day-to-day forecasting as in preparing forecasts for a longer time in advance, allowance is made by the forecaster for the difference in time.

The weather elements generally shown on synoptic charts are the following: Pressures corrected for temperature and reduced to sea level; air temperatures; the direction and speed of the wind, the former by a symbol and the latter in numerical values; the state of the sky, whether clear or cloudy, and the degree of cloudiness; and the state of the weather at the time of observation, whether raining, snowing, sleeting, or foggy. The amount of precipitation, if any, is entered as the last group of figures. The character of the observational data spread upon the synoptic chart has not materially changed in the last fifty-odd years.

The next step in the construction of a synoptic weather chart is to generalize the data entered thereon by drawing lines through points having the same value of pressure or temperature. These lines are called isobars and isotherms, respectively. It is customary to draw isobars and isotherms for steps or intervals of a tenth of an inch of pressure when English units are used and for 10° of the Fahrenheit scale. In drawing both sets of lines the process known as interpolation comes into play. Thus if one is drawing the isobar of 30 inches and the pressure at the station is exactly that amount, the isobar, will pass directly through the station; if, however, the pressure is 29.96 inches, the isobar must then pass above or below the station according as the pressure at near-by stations is greater or less than 30 inches. A little practice will enable one to draw these lines accurately and quickly.

After the isobars have been drawn it will be found that at some points pressure is low and at others high. It is customary to mark these places "LOW" and "HIGH," thus signifying the centers of areas of low and of high pressure, respectively. These terms are synonyms for "cyclones" and "anticyclones," names applied by meteorologists many years ago to designate the two most common contrasting pressure conditions. (See p. 16.) The isobars which give form and shape to cyclones and anticyclones may be thought of as being analogous to the contour lines on a topographic map, the high pressure corresponding to the hills and the low pressure to the valleys, and since there must be a valley between two hills the analogy may be pushed farther, and it will be found that in general cyclones are followed by anticyclones, but the sequence is not an invariable one. The warning should also be given that each spot marked "LOW" or "HIGH" as the case may be, does not necessarily mean that each is a full-fledged cyclone or anticyclone.

The reason why cyclones and anticyclones or the LOWS and HIGHS of the weather chart have such an important bearing on weather forecasting is because of the pronounced contrast in the weather associated with them. If it is known that a cyclone is advancing upon a region it is assured within slight variations depending upon the season that the winds will be stronger than the average, the sky will be cloudy with rain or snow according to the time of year, and the temperature will be higher than usual. After the cyclone has passed and the anticyclone has come on, precipitation of rain or snow ceases, the sky, as a rule, clears, the wind shifts to a northerly

or westerly quarter, and the temperature falls. The northerly component of the wind continues for several days and then shifts to an easterly or southerly quarter, thus indicating the coming of another cyclone, and the sequence of weather is repeated.

The chart considered up to this time is commonly known as the "weather" or principal chart; it is the endeavor to put as much on it as the space will permit, but the need for other helpful information compels the construction of auxiliary charts in every large forecasting unit. These charts generally afford the forecaster an easy method of viewing the changes that have taken place in the pressure, temperature, or what not in 24 hours or since last observation.

WEATHER BUREAU AUXILIARY CHARTS

The Signal Service in 1877 began the construction of what was then called a "pressure change chart." It showed the changes in pressure in the last 24 hours, also the more immediate changes—those since last observation. Three such charts were made at intervals of eight hours daily. These charts fulfill, substantially, the rôle played by the isallobaric charts featured by Ekholm (*5*) and described in the Hann-Band of the Meteorologische Zeitschrift, 1906.

The auxiliary temperature chart was begun in 1879. It shows the current temperature, the highest and lowest in 24 hours, the variation from the normal of the current temperature, and the 24-hour change.

The auxiliary cloud chart shows by symbols the kind, amount, and direction of movement of the several cloud forms observed, and a suitable symbol is used to indicate rapid movement. The form in which the data of clouds has been charted has been changed rather frequently, and the quantity of the data telegraphed has also varied from time to time. At one time only data regarding the high or upper clouds were telegraphed.

The latest auxiliary chart to be added to the forecasters series is that known as the aerological chart, based on free air observations by means of pilot balloons that give the speed and direction of the wind at *70* stations at the surface and also in the free air at steps of 250, 500, 1,000, 1,500, 2,000, 3,000, and 4,000 meters. The kind and direction of movement of clouds that were observed at the same time is also reported. This chart also shows the data obtained from five kite stations and two naval airplane stations. Changes in temperature and moisture with altitude as determined with kites are graphically shown in the form of temperature-altitude diagrams that form insets on the chart.

Kite flights were inaugurated at 15 stations by the United States Weather Bureau, in 1898, and discontinued after the lapse of a year. They were revived at Mount Weather, Va., in 1907, and discontinued at that station in 1914. In the next year they were again revived at Drexel, Nebr., and other stations were established from time to time. The results of kite flights have been telegraphed to the central office of the Weather Bureau in Washington, D. C., for use in the forecast division from 1907 to date.

Other auxiliary charts have been prepared from time to time only to have been abandoned when their usefulness became questionable. The element that caused a great deal of experimenting was the air moisture. Relative humidity was charted for a while and later

revived in the form of vapor pressure charts, and it is not so many years ago that these were abandoned.

In assessing the value of the different auxiliary charts forecasters are pretty generally agreed that the pressure change chart is the most valuable.

EARLY FORECASTING IN THE UNITED STATES AND ABROAD

In 1871, when official forecasting in the United States was begun, no precepts were at hand for the guidance of the new service, and knowledge on the subject was extremely limited. It is probable that the groundwork for the new service was furnished by the Fourth Meteorological Report by James Pollard Espy (1785–1860) (*6*), made in October, 1852, addressed to the Secretary of the Navy. By him it was transmitted to Congress, on call, referred to the Secretary of the Smithsonian Institution, ordered printed, published in 1857, and reprinted several times by the Signal Service under the title "Suggestions for the Practical Use of Meteorological Reports and Weather Maps." This report contained practically all of the trustworthy information in regard to the movement and behavior of storms in the United States then available. And this report, together with the conclusions of William C. Redfield, an independent investigator, must have formed the basis on which forecasts and warnings were issued.

A record of the names of the early forecasters of the Signal Service has not been preserved. The following list is made from personal recollection and other sources. A roster of the Army officers who served as forecasters would read as follows: Craig, Greely (who later became Chief Signal Officer), Dunwoody, Story, Allen, Kilbourne, Woodruff, Thompson, Powell, Glassford, and Finley. The civilian forecasters of the same period were Lapham, Abbe (the originator of the system), and H. A. Hazen, who came in 1887. The record does not show whether Thompson B. Maury, who was an assistant in the early years, ever took an active part in official forecasting; but it is probable that he did.

With the transfer of the meteorological work of the Signal Service to the newly created Weather Bureau in the Department of Agriculture in July, 1891, there was a provision of Congress that permitted the detail of Army officers skilled in forecasting to the Weather Bureau. This provision was repealed by the joint resolution of July 8,1898.

At this time it may be profitable briefly to review the progress made in weather forecasting in the fifty-odd years that have elapsed since the beginning in 1870.

PROGRESS IN WEATHER FORECASTING SINCE 1870

Progress in weather forecasting may be expressed in numerical units and in other ways. The Army Signal Service in the beginning divided the United States into 11 districts for the purpose of issuing the daily synopsis and probabilities as they were then called. The term "probabilities" was changed to "indications" in 1876, and that term was followed by the present "forecasts," adopted in April, 1889. The original forecast districts were rather large, each one comprising several States, for example, the "Middle Atlantic" comprised New York, New Jersey, Pennsylvania, Delaware, Maryland, the District

of Columbia, and Virginia. A forecast for so large an area must of necessity have been stated in very general terms.

An improvement resulted when the Signal Service began to issue forecasts for the individual States and parts of States, a custom that was continued by the present Weather Bureau. The Signal Service also made a beginning in extending the time of the forecast beyond 24 hours, but it left it optional with the forecaster as to whether or not he should make the longer period forecasts when the weather conditions were not favorable. The Signal Service also inaugurated the practice of local forecasting by competent station officials.

It also recognized the advantage that would accrue in the local distribution of the forecasts and warnings from decentralizing the Washington forecasts for regions remote from that city. Thus Robert Craig, of the army group of forecasters, was sent to San Francisco, Calif., and began the issue of forecasts and warnings for

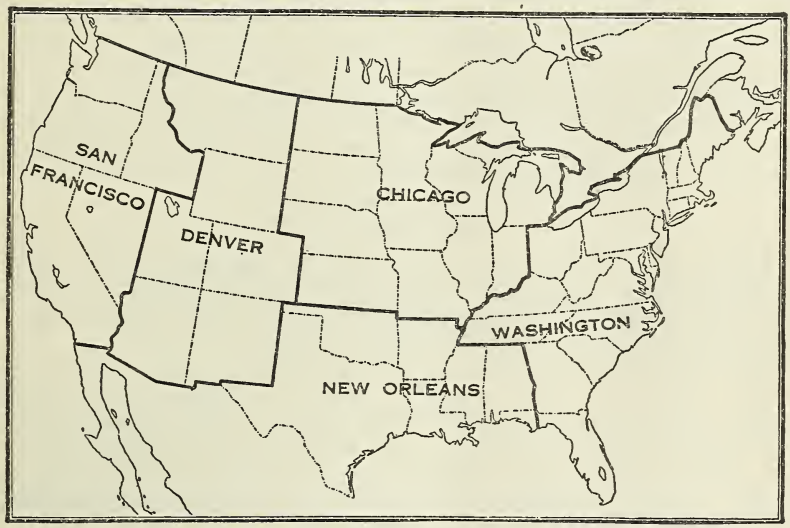


FIGURE 2.—Forecast districts in 1929

Pacific Coast States in April, 1885; other forecasters for those States succeeding Craig were Lieutenants Glassford, Maxfield, and Finley.

At the time of the transfer of the weather service from military to civil control San Francisco was the only district center outside of Washington, D. C. In the early nineties and in subsequent years district forecast centers were established at Chicago, Ill.; Galveston, Tex., later transferred to New Orleans, La.; Denver, Colo.; Portland, Oreg.; Louisville, Ky.; and Boston, Mass. Three of these districts have since been consolidated with adjacent districts. See Figure 2 for the districts existing in 1929.

In the beginning the district centers outside of Washington except San Francisco made morning forecasts only, night forecasts being made and distributed from Washington. The forecasts made at the several centers are known as "State" forecasts, and these are sent to the local Weather Bureau offices for distribution. Officials in charge of local stations may within certain limitations amplify the

State forecast the better to adapt it to the local needs. In some cases the local official or his first assistant may make local forecasts.

A comparison of the numerical results showing the percentage of justification attained under the two régimes, the Army and the civilian, is favorable to the civilian, as would be expected when it is remembered that the field of observation originally confined to the territory east of the Rocky Mountains has been expanded until now it covers practically the whole of the Northern Hemisphere from the meridian of Greenwich to about 160° west longitude and from 10° north latitude to the Arctic Circle, although the stations in high latitudes are as yet far too few in number.

It should be said for the Signal Service régime, however, that it developed from crude beginnings a system of forecasts and warnings that has continued up to the present without radical change. Progress has been made in reading the indications from the weather charts, the field of observations has been wonderfully extended, especially by the help of radio reports from the oceans, and experienced forecasters have been kept on the work more or less continuously, thus securing the benefit of added experience and more mature judgment.

While the general principles on which weather forecasts are based have not changed materially, there has been marked progress in recent years along the line of what may be called specialized local forecasts. These are discussed below.

SPECIALIZED FORECASTS

Specialized forecasts are so called because they are the direct result of attempts to concentrate and apply the knowledge of weather forecasting to certain specific products or crops with a view of improving their condition and eventually the yield.

They are in force only in restricted localities where a particular product finds its most congenial habitat. Thus the fruit-spray forecast, which attempts to give the orchardist three days' notice of the coming of rain, is made for the apple district of western New York, Door County, Wis., and the apple districts of Michigan and Indiana. Below is given a categorical list of the several specialized forecasts made by the Weather Bureau.

Fruit-spray forecasts.—For the districts enumerated above.

Fruit-frost forecasts.—Made in connection with special services for the following-named regions: The Sacramento and Santa Clara Valleys, Calif.; lower Colorado Valley, Salt River Valley, Ariz., Gunnison and Uncompahgre Valleys of Colorado and upper Pecos Valley, N. Mex., upper Rio Grande Valley, N. Mex., Florida, and Delaware.

Special rain forecasts.—For benefit of raisin growers of San Joaquin Valley, Calif., in raisin-drying time.

Alfalfa harvest forecasts.—For benefit of alfalfa growers in Utah.

Cranberry growers forecasts.—For the benefit of cranberry growers in protection from frost in the cranberry districts of Massachusetts, New Jersey, Wisconsin, and Washington.

Rice growers forecast.—For rice-growing districts in Arkansas and Louisiana.

Tobacco growers forecasts.—For parts of New England.

Lambing and sheep-shearing forecasts.—Made for certain far Western States in season.

GENERAL FORECASTS AND WARNINGS

In addition to the above-mentioned specialized forecasts the ordinary day-to-day forecasting program as carried on at the five district forecast centers (fig. 2) includes a forecast of wind, weather, and

temperature for each State in the district. This forecast is made twice daily from observations at 8 a. m. and 8 p. m. eastern standard time. These forecasts are known as the "State" forecasts. They are rapidly distributed to each local Weather Bureau office in the State, and by the local officials in charge are further distributed locally. The officials in charge, above a certain rank and also those in charge of the larger stations and their first assistants are authorized to make local forecasts, but as a rule the State forecast is used at the great majority of stations, except that the official in charge may amplify it in the interest of local needs.

ADVICES AND WARNINGS

The twice-daily forecasts just enumerated also carry advices and warnings as to the occurrence of high winds and gales on the Great Lakes and along the coast of the Gulf of Mexico and both seaboards. The visitation of the coastal regions of the Atlantic south of the fortieth parallel of north latitude and the Gulf of Mexico by tropical cyclones is forecast in the regular program. This program also carries in season the shippers' forecast, made by local officials, warnings of frost and freezing weather in the sugarcane region, frost, and the occurrence of cold waves in districts where needed. Forecasts of cold waves and stormy weather in stock-raising States are also made as a special feature of the forecasting program.

In far-western States the occurrence of conditions favorable to the occurrence of forest fires is a regular feature of summer forecasting.

Many of the foregoing items may be set to the credit of improvements in weather forecasting in recent years, to which should be added the extension of the time limit from 48 hours to a week.

The question as to whether forecasting from synoptic charts in general has improved will be touched upon in the concluding paragraphs of this section.

For the region of North America, at least, there has been improvement, although there are yet failures—failures to accurately indicate the weather of the morrow. Such failures, it may be pointed out, are due to the inherent weakness of the system of forecasting the weather from synoptic charts. It is true that free-air observations are being made and used in increasing number, but the total number as compared with those available for the surface is pitiably small, and, moreover, forecasters have yet to learn to correctly correlate free-air conditions with the sequence of the weather 24 to 36 hours later—no mean undertaking.

WEATHER FORECASTING ABROAD

A detailed history of the development of weather forecasting in Europe and Asia has not been and perhaps never will be written. Obviously it can only be done by one having access to the records of private and official observatories and institutions in the several countries in those parts of the globe. The views about to be expressed are drawn from two historical incidents presenting the state of the art, first in the early nineties and again in 1923.

The first is due to the initiative of the late W. J. Van Bebber (1841–1909), for many years associated with the Deutsche Seewarte at Hamburg. Van Bebber was the author of many papers on mete-

orological subjects and was particularly interested in the paths followed by barometric depressions that passed over Europe. He was also the author of a treatise on forecasting that was and perhaps may still be used in European countries. In the early nineties (precise date unknown) he addressed a questionnaire to directors of weather services in Europe and North America that called for specific replies to the following three questions:

(1) The degree of accuracy of forecasts of temperature, rain, and wind for one, two, and three days in advance.

(2) The principles on which the forecasts depend, and the character of the weather you are able to predict.

(3) The advisability of predicting rain, and the extent to which we should predict temperature or other changes, viewed from the standpoint of what it is possible to predict with a fair degree of success and what the public cares to know.

Van Bebber, himself, held what in the light of subsequent development proved to have been conservative views on the ways and means to improve weather forecasting in European countries. He was of opinion that the fundamental principles of the art are the same everywhere; that the pressure and its day-to-day changes hold the key to successful weather forecasting.

The replies to question No. 2 are particularly interesting, since the section of meteorology of the International Union of Geodesy and Geophysics at its Rome meeting in 1924, propounded a somewhat similar question concerning the principles on which forecasts for a certain day in September, 1923, were made.

The great majority of the replies received by Van Bebber gave rather full information on question No. 1, but very few replied to No. 2.

Replies were received from the following organizations: Canadian Meteorological Service, Danish Meteorological Institute, Norwegian Meteorological Institute, Central Physical Observatory of Russia, the weather service in Austria, Hungarian Meteorological and Magnetic Bureau at Budapest, the weather service of the Netherlands, London Meteorological Office, Berlin Weather Bureau, unofficial, Forecast Service of Switzerland, and United States Weather Bureau.

In all, 11 replies were received. Only three of them touched at any length upon the principles on which forecasts depend, namely, those from Canada, the London Meteorological Office, and the United States Weather Bureau.

In 1924 replies to a similar question were received from 17 countries or institutions. The failure of all but 3 of the 11 organizations questioned in 1893 by Van Bebber is interpreted to mean that weather forecasting in those countries not replying was not on a firm basis.

The writer quotes largely from the replies from the Canadian Meteorological Service and the London Meteorological Office to Van Bebber's question No. 2 in 1893.

From Canada, 1893, R. F. Stupart, predictions officer:

The forecasts as issued from Toronto depend altogether on a knowledge obtained from practice and study of the movements of areas of high and low pressure on this continent, and the weather which, under various circumstances, accompanies these areas, taking fully into account in predicting for certain districts the influence that winds of different directions and increased or diminished moisture will have in various cases.

The predicting officer has by experience learned much as to the influence that areas of high pressure and of low pressure will probably have upon each other as regards development or dispersion and rate of movement, and makes his pre-

dictions on the basis that the pressure changes will be as he anticipates. It is not an uncommon thing for him when an abnormal movement of a cyclone has occurred to base a prediction on the assumption that such movement was either directly or indirectly caused by another cyclone beyond the region of observation, for instance, at sea, and in this manner many storms on our seaboard have been foreseen, the existence of which would not have been expected.

From Canada, 1924, Sir F. Stupart, after describing the charts and other material available, says:

Charts showing the trajectories of typical areas have been prepared and are available for consultation in doubtful cases, and the barometric tendency is at times found to be useful aid toward reaching a conclusion as to probable changes. An experience extending over several years has been found to be quite essential to really successful forecasting and each forecaster is required to spend at least three years in preparing and studying the daily maps, before he is permitted to issue forecasts.

London Meteorological Office, 1893, F. Gaster, chief of forecast division:

With regard to the principles adopted, they depend mainly upon a recognition of the well known characteristics of cyclonic and anticyclonic systems, primary, secondary, or V-shaped, and upon the indications afforded by the three daily observations as to their movements and the questions of their tendency to increase or decrease in area or intensity.

The general distribution of pressure (also whether favorable for a continuance of cold or warm, dry or wet, currents of air), the effects of such currents when coming from off the sea or vice versa, the relatively rapid movement of air on coasts when compared with that over land, and the variations produced by the seasons on such phenomena, are all carefully thought out before preparing the forecasts or issuing warnings, besides the question whether the disturbances are of a "thunderstorm" or similar character.

London, 1924, G. C. Simpson:

The instructions for the meteorologists who make the forecasts are found in the pamphlet by R. Abercromby and are amplified in "Forecasting Weather" by Sir N. Shaw.

The changes in pressure that are indicated by the barometric tendency and the changes in wind direction are the principal considerations in the forecasts of the weather to follow. The meteorologist relies on his personal experiences, aided by reference to typical cases which are indicated in Geophysical Memoir No. 16 (M. O. 220f), Aids to Forecasting: Types of pressure distribution with notes, etc., by E. Gold. Account is also taken of the distribution of temperature in relation to the theory of the "polar front" by V. Bjerknes. There is kept for ready reference a file of synoptic charts of the whole world.

When he has formed an opinion as to the probable changes of pressure the forecaster fills in the details of the prognosticated weather in accordance with the type of isobars that is expected in a particular region during the period of the forecast. Account is taken of the vertical and horizontal distribution of temperature in the formation of clouds and rain.

These forecasts are for a period of 30 hours; there is added a "further outlook" for several days in advance when the conditions appear to justify such inference.

United States Weather Bureau, 1893, H. H. C. Dunwoody,[1] chief of forecast division:

While a thorough knowledge of general meteorology and of the conditions peculiar to the various districts or localities for which the forecasts are made is a recognized qualification, the forecaster must possess the ripe judgment gained by experience, and the confidence and aptitude which nature alone bestows, in order to become eminently successful in the practice of weather forecasting. The principles upon which the forecaster depends are embodied in the application of these necessary qualifications to a solution of the problems presented by the weather maps. The tabulated data [not here reproduced] show the degree of

[1] With the transfer of the meteorological service from the War to the Department of Agriculture in 1891, provision was made to retain for a time officers of the Army Signal Corps, skilled in forecasting, so that in 1893, the forecasting activities of the Weather Bureau were still in the hands of Signal Corps officers.

success attained in predicting the several changes or character of weather covered by the forecasts. Rain or snow forecasts are admittedly the most uncertain and are the forecasts which yield the lowest percentage of verification; yet this class of predictions is undoubtedly of the greatest importance.

United States Weather Bureau, 1924, C. F. Marvin, Chief.

Forecasters of the Weather Bureau find the distribution of pressure at the moment and especially the changes which have taken place within the 12 hours immediately preceding the observation hour most helpful in the issue of forecasts and warnings. The chief reliance of the forecaster, however, is his experience and the natural ability he possesses of interpreting the indications of the weather map. Portions, at least, of the polar front theory of V. Bjerknes have been successfully used in the practical work for a number of years.

These two cross sections of the forecasting activities of the English-speaking peoples show that there is general agreement in the principles used and that special emphasis is laid upon the personal experience and natural ability of the forecaster.

PROGRESS IN OTHER COUNTRIES

Perhaps the single outstanding event in the practice of forecasting during the last fifty-odd years is embodied in the new ideas of the mechanism of the cyclone as developed by the Meteorological Institute of Bergen, Norway.

During the World War meteorological reports from outside countries were denied Norway; as a consequence she organized a very close network of meteorological stations in her own territory, many of them making noninstrumental observations. From the reports of this very close network of stations the Norwegian forecasters were able to distinguish two fundamental lines of discontinuity that meet at the center of the cyclone. The names given these lines were the "steering" line, more recently the warm front, and the squall line or cold front. Investigation showed that these two lines were distinguished by characteristic thermal properties. The steering line or warm front comes into the cyclone from an easterly direction and stands in close association with the well-known fact that the air in front (eastern) of a cyclone is warm. The squall line in the rear of a cyclone marks the advance of cold air from higher latitudes that invades the region of warm air of the cyclone (the warm sector). The squall line is also known as the cold front. Thus the modern terminology of the cyclone concerns itself with fronts and their effect on the weather.

These two lines of discontinuity or lines of separation between air masses which are warm when of southern origin and cold when of polar origin meet in the center of the cyclone. The warm-air mass is being continuously renewed from lower latitudes when the conditions are favorable to the continued life of the cyclone, but it is also quite as continually being attacked in the rear by the flow of colder air from higher latitudes. On the eastern side of the cyclone the warm air is forced to ascend upon a wedge-shaped mass of colder air and the cooling thus brought about is the cause of the rainfall termed "warm" front rain. In the rear of the cyclone the colder air of polar origin undercuts the warm air in its path, forces it upward, and likewise produces rainfall, so that the Bergen nomenclature also takes account of what it calls "cold" front rains. In the older view the rains associated with a cyclone were considered as "cyclonic" rains simply without further differentiation.

In many respects the new conception harks back to Dove, who in the middle of the nineteenth century pictured the weather as being due to the conflict between currents of equatorial and polar air, respectively. The word "front" moreover connotes a skirmish line between opposing forces and is appropriate to the conception of the results which flow from the juxtaposition of air masses of different temperature and moisture content.

The Norwegian school has given us, among other things, a simple explanation of the fact that occasionally cyclones cease to function as such. Briefly, the explanation is based on the fact that at times the advance of cold air in the rear of the cyclone is so rapid as to completely cut off the supply of warmer air that feeds the central region of the cyclone. The cyclone is then said to be "occluded" and soon expires.

THE PRACTICE OF WEATHER FORECASTING

One of the first things that came out of the use of synoptic weather charts was the recognition of two characteristic pressure formations, to which the names "cyclone" and "anticyclone" were given. The daily weather chart, however, continues to use the synonymous terms "LOW" and "HIGH."

In the United States, unfortunately the word "cyclone" has been used in the public prints as the name of the very intense local whirl properly called a tornado. (See page 72.) For nearly 25 years the Weather Bureau has sought to correct this abuse of the term "cyclone" but without much success; the fact is mentioned in order that there may be no confusion on account of the term "cyclone" as used in this publication.

A cyclone is, first of all, a system of whirling winds around an area of low pressure. The low pressure may be of very great horizontal extent—1,000 miles or more in diameter but extending upward not more than 2 or 3 miles, thus forming a saucer-shaped mass of air which moves over the earth's surface at a velocity of 30 to 40 miles an hour in winter and less rapidly in summer. The winds in the Northern Hemisphere blow spirally inward around the center of lowest pressure in a direction contrary to the movement of the hands of a watch as it rests upon a table face upward; the movement of the winds is then said to be counterclockwise. In the anticyclone the movement is just the opposite of that described, or in a clockwise direction.

In the Southern Hemisphere the direction of movement of the wind in cyclones and anticylones is the reverse of that above described.

The important difference between the two formations is in the weather associated with them.

In the Northern Hemisphere winter the sun is over the Southern Hemisphere, the temperature of the north polar regions sinks to a minimum, and the contrast in temperature between polar and tropical regions is greatly increased, thus giving more power to the driving force of the general wind circulation. To this increase is due the strength and vigor of the winter circulation as compared with that in summer, when the contrast in temperature is least.

As the general winds of both hemispheres increase in strength during the winter, the intensity of cyclones and anticyclones also increases and reaches a maximum in that season. The chief effect of cyclones

and anticyclones is to interchange the warmer air of lower latitudes with the colder air of higher latitudes, and it is through this mixing process that the very great variety of weather is experienced in temperate latitudes.

It may be remembered that the cyclonic circulation is associated with a flow of warm and moist air from the south on its eastern side and that the anticyclone is the medium whereby cold, dry, continental air is transported equatorward on its front or east side. A realization of these two simple facts will do much toward a clear understanding of weather phenomena.

In a cyclone the strength of the wind is roughly proportional to the pressure gradient. The term "pressure gradient" refers to the pressure slope in the same sense that an engineer uses the word to indicate the slope of an area by the contours of a topographic map. When the barometer is very low in the center of a cyclone, or very high in the center of an anticyclone, the slope or the pressure gradient between them, if they are close to each other, will be steep, and the winds will be correspondingly strong. Roughly speaking, the closeness of the isobars on a weather chart gives an approximate value of the strength of the winds.

From rather intimate contact with the features of cyclones and anticyclones as gained by 60 odd years of experience, meteorologists have arrived at a rather full knowledge of their shape and travel and other characteristics, but as yet little is definitely known as to their origin and maintenance. Some forecasters regard the anticyclone as the dominant twin of the pair, and others hold to the contrary view, but modern students think more in terms of cold-air masses and warm-air masses than of anticyclones and cyclones.

Sir Napier Shaw (*15, p. 347*) gives some idea of the complexity of the problem when he says:

> So with our cyclones, one of the essential elements of the problem is to decide what is the entity which travels. If it is a vortex we have to make out how it is protected against rapid dissipation, how the material of the vortex, or what part of it, is permanent, how it takes in or rejects material and energy during its travel. And, on the other hand, if it is a wave we have to explain why the section of it at the surface over which it travels is so much like a vortex with a vertical axis.

THE PLACE OF ORIGIN OF CYCLONES

The place of origin of cyclones is of some academic interest but not of great practical importance in any large forecast unit. The most complete statistical presentation of data of origin and movement of cyclones of the Northern Hemisphere is that in the Weather Bureau Bulletin entitled "A Summary of International Meteorological Observations" (*4*). This summary was based on the noon Greenwich mean time observations collected by the Signal Service during the years 1875–1887.

It is evident from a study of that publication that cyclones may originate anywhere around the globe in the Northern Hemisphere, except on the Equator. Some localities, however, appear to be more favorable than others, the most favorable appears to be over the oceans a short distance to the eastward of the great continents. Their movement is substantially around the world except as the interior of northeast Siberia presents especially in winter the most inhospitable terrain to both man and cyclone found in any part of the globe, and thus the complete circuit of the globe is prevented.

A page might easily be written in explanation of why cyclones do not easily traverse eastern Siberia, but it does not seem advisable to dwell on that particular phase of the subject.

The general storm track, as is indicated in the publication above mentioned, begins in the Indo-China region, approximately in north latitude 37° and east longitude 142°.

The aggregate number of storms in that location for 10 years is 188, or an average of 19 a year. The general track continues in a northeast direction, passing to the eastward of Japan and continuing across the Pacific to the Gulf of Alaska and the Aleutian Islands.

Cyclones do not pass readily directly from the Pacific Ocean over the Continent of North America, but secondaries become detached from the primary oceanic cyclone, and these pass across the continent, reaching a maximum frequency in the Great Lakes region where the aggregate number in 10 years in a single 5° square amounted to 481 storms, or an average of 48 a year. Crossing the North Atlantic, the general path bifurcates, a portion of the storms taking a northern course and another part taking the southern course over the Mediterranean. The average number of storms over the Atlantic just west of the British Isles is 20 a year; and over northern Italy, where there seems to be a secondary maximum, it is 18, or about the same as that in the Indo-China region before mentioned.

Mitchell (in an unpublished manuscript), using the observations made on board the *Maud* while she was frozen in on the Siberian coast in the winter of 1924–25, in north latitude 70°, east longitude 142° 25′, plotted the cyclones that could be distinguished from Asiatic weather maps for the four months January to April, inclusive, 1925, and also found a maximum development of cyclones in the Indo-China region.

There are nine groups of cyclones. Alberta [2] cyclones, so called because with the limited number of reports available up to recent times they were first charted in the Canadian Province of that name, are the most numerous of all groups, and unlike the other groups they are rather uniformly distributed throughout the year, there being about as many in summer as in winter. In the nine groups as a whole, the season of greatest storminess is October to April, inclusive, with the largest average number in December and January, approximately eight a month. In the remaining months of the year, May to September, inclusive, the average number is six storms a month.

Two Pacific groups are distinguished merely because the storms of the south Pacific group enter the continent south of north latitude 40°. Generically both groups are identical, but those of the southern group because of unfavorable pressure distribution, or what not, are forced farther to the southward over the ocean and thus enter California at or south of San Francisco. These storms because of the rainfall they bring are of very great economic significance to southern California. Storms in Alberta and the two Pacific groups, form about 60 per cent of the total number. Practically all of the winter storms in the Alberta group come in from the Pacific or develop as

[2] Mitchell suggests the abandonment of the term "Alberta" cyclone, since, as he says, "they are seldom, if ever, now charted as first appearing over the Province of that name." He considers them as being either primary cyclones of Pacific origin or secondaries therefrom.

secondary cyclones from primaries of Pacific origin. The warm-season Alberta cyclones are less well defined than those of winter, but probably should be considered as developing over the ocean along the northeastern periphery of the great north Pacific anticyclone which makes its greatest northing at this season.

The remaining groups—northern Rocky Mountain, Colorado, Central, Texas, East Gulf, and south Atlantic—are made up mostly of secondary cyclones which develop over the land in connection with oceanic cyclones (Pacific) that are unable to pass inland in their entirety. Some of the Pacific cyclones, especially those of winter, endure long enough to be traced across the continent and pass thence over the Atlantic on their way toward Europe; a rather large percentage, however, can not be traced directly inland as active going storms, and this is especially true of those large cyclones of the Gulf of Alaska that rarely, if ever, pass inland in their entirety, but give off at times one or more offshoots that may or may not become active going storms.

MOVEMENT OF CYCLONES AND ANTICYCLONES

Tropical cyclones north of the Equator, to which the terms "hurricanes" and "typhoons" are applied in certain parts of the world, move west-northwest from latitudes near to but not on the Equator to north latitudes 20° to 25° in the Western Hemisphere, whence they recurve and move to the northeast. While in the Tropics these storms move much slower than the cyclones of mid latitudes.

Extratropical cyclones on an average of the year move with a speed of 28.6 miles per hour, using Von Herrmanns's values; the speed, however, varies from an average of about 35 miles per hour in winter to about 24 miles per hour in June. Individual cyclones may move with much greater speed, cases being on record that show a movement of as much as 60 miles per hour or more. The writer has investigated some of the fast-moving cyclones and found, in a number of cases, that the speeds were apparent rather than real. There is often a readjustment of pressure that results in the displacement of the center of low pressure great distances in a short time. It is not believed that in these cases there was an actual progression of the entire system of whirling winds at a high speed across the country, but rather that the inherent faults in the system of plotting the paths of cyclones in past years is responsible for the extraordinary high velocities. Of course, as remarked elsewhere, an alternative view is always present, viz, that the cyclone may move in and with the speed of the air currents 1 or 2 kilometers above the ground surface, in which case a rapid movement may be expected.

In this connection the remarks of *Shaw* and *Lempfert* (*16*) on the progress of cyclonic storms are quoted:

> The apparent progress of the center may be the result of constant development of a fresh system more or less similar to the existing one, but of new materials in the front and a corresponding decay in the rear.

The speed of anticyclones is not so accurately known as that of cyclones, but is not far from 26 miles per hour in January, falling to about 20 miles per hour in June.

The movement of cyclones and anticyclones seems to coincide roughly with that of the general winds in which they travel and of which they are doubtless a part.

Inasmuch as forecasts are generally based upon the previous movement of these barometric formations it becomes exceedingly important to discover the cause or causes of departures from that movement. Indications as to the future course and speed of movement of cyclones may be sought in the amount of the pressure fall since last observation, the surrounding or local pressure distribution, and the surface temperatures. It is possible at times to anticipate a rapid movement of both formations, and the novice, regardless of temporary discouragement, should pursue the study until a measure of success is attained.

The cyclone is best developed and sustained over a water surface, and it sustains a marked loss in intensity when passing inland over the great continents, especially when the contrast between the temperature and moisture of oceanic and continental air is greatest.

Along the Gulf coast and also along the Atlantic coast south of Virginia, the entrance of both tropical and extratropical cyclones is easily accomplished without very much loss of intensity, except in the case of the first named, which suffers a loss in intensity after passing over about 100 miles, more or less, of land surface.

The paths followed by cyclones tend in general toward the east or east-northeast in the eastern part of continents and east-southeast in the western part, although a small number advance from the Washington and Oregon coasts southeastward to the vicinity of the Gulf of Mexico, thence move to the northeast, passing out to sea over the Gulf of St. Lawrence, if they endure long enough. It is estimated that at least 30 to 40 per cent of the cyclones that appear west of the one-hundredth meridian do not survive long enough to cross the continent.

Anticyclones, on the other hand, come in the main from the higher latitudes of Canada and from the Pacific in the neighborhood of Washington and Oregon. Anticyclones have a greater or less southerly component of motion, some moving almost due south over the Plains States but the large majority moving southeastward by way of the Missouri Valley to the middle Mississippi Valley and then spreading eastward, depending for the exact direction of movement upon the pressure distribution at the moment.

FORM OF ISOBARS IN CYCLONES AND ANTICYCLONES

The fact that the form of the isobars is rarely or never precisely the same on two successive maps is illustrative of the continuous change in weather phenomena. The change is due to two principal causes: (1) The general movement from west to east, which involves the passage of the cyclone into and over areas with different topographic and climatic conditions; and (2), changes from one day to the next in the intensity of the pressure formation (and by intensity the writer has in mind the up and down changes in the pressure in the center of a cyclone). Pressure may sink lower and lower as it progresses into regions where the elements are favorable to such a change, and on the other hand the pressure in the center may rise—a sure indication that the cyclone is filling up, so to speak.

The student of the weather chart will soon discover that the isobars have a habit of arranging themselves in a variety of forms. Two of these have already been described, the cyclone and the anticyclone. For the beginner the remaining forms will have merely an academic

interest. The principal forms are shown in Figure 3, following Abercromby. They are as follows:

(1) The cyclone, an area of low pressure bounded by circular or oval isobars.

(2) The secondary cyclone, a small generally circular depression of the barometer that frequently develops a little to the south and east of the principal cyclone as the latter begins to disappear. A secondary may also be indicated by a loop or bulge in the isobars of the primary.

(3) The V-shaped depression, an area of low pressure, bounded by V-shaped isobars, a rather important type.

(4) The anticyclone, an area of high pressure bounded by isobars, sometimes oval, again circular, and at still other times a greatly elongated oval.

(5) Wedge-shaped isobars, an area of high pressure bounded by isobars that converge to a point like a wedge.

(6) Straight isobars, a barometric slope down which the isobars lie in nearly parallel lines.

(7) The col[3] or neck of relatively low pressure, lying between two adjacent anticyclones.

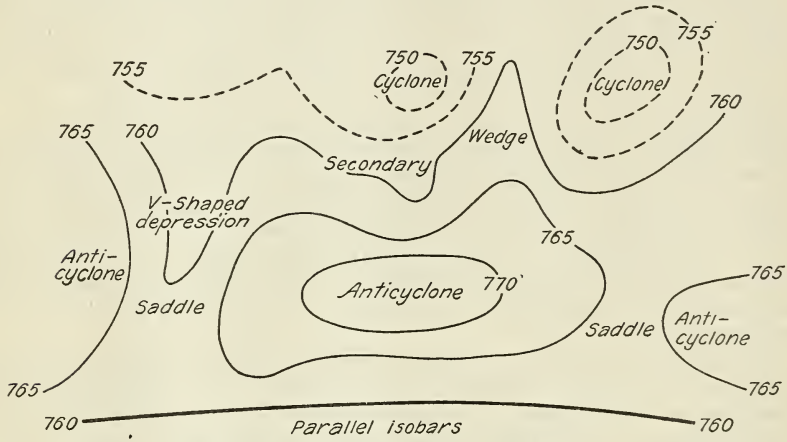


FIGURE 3.—Form of isobars, after Hann and Suring

CLASSES OF CYCLONES

Cyclones have been divided into two great classes, tropical and extratropical, because of certain pronounced differences between them, set out elsewhere in this publication. In the United States the average number of extratropical cyclones as determined from a 21-year period is about 1 every three days, or roughly 122 a year (*2, p. 7*). In Europe and Asia the number is probably less, say 1 every five days, or 73 a year, so that for the Northern Hemisphere an estimate of 200 a year is not greatly out of the way. For the Tropics, Fassig (*7, p. 15*) puts the number of tropical cyclones at 34 a year.

Any one of the stereotyped forms of pressure distribution before enumerated may appear in a more or less modified form, and the student will soon discover that a large number of the barometric formations encountered in the run of a year's charts almost defy classification.

Several forecasters and others have advocated the classification of weather maps in types or families for use in daily forecasting. If the number of types does not become too great this method has its

[3] This term has been replaced in the German by "Sattel." Bigelow and others use the English equivalent, Saddle.

application, and in any event the labor of classification is a worthwhile exercise for the beginner.

The V-shaped depression calls for careful study by the novice because it oftens contains much potential bad weather in the way of severe thunderstorms and squall winds as the wind shifts from southerly to northerly.

Much might be written on the formation of a secondary depression.[4]

Ideas as to the mechanism of cyclones and anticyclones, always more or less hazy, have undergone material change in the last quarter century. Figure 4 is representative of the views of the wind circulation between them as deduced by Bigelow (*1*) in 1897. The explanation of the construction is as follows:

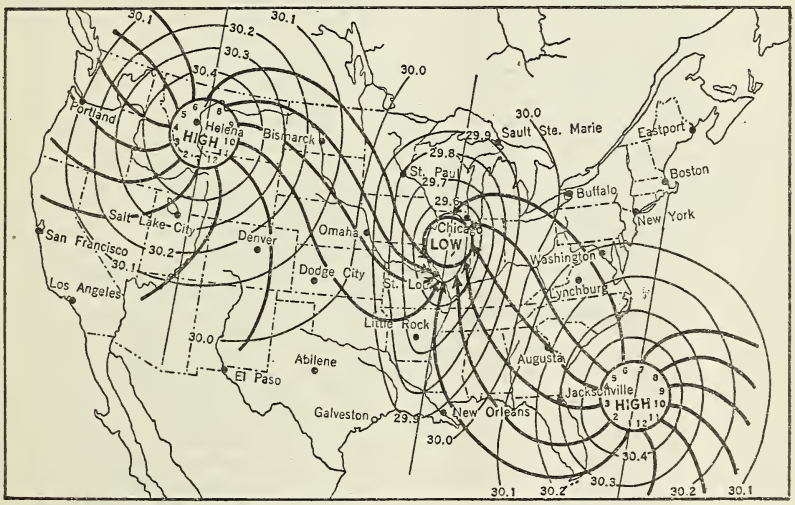


FIGURE 4.—Isobars and wind streams, after Bigelow 1897

Chart 8 (fig. 4) has been carefully constructed, and represents the average condition as derived from 10 fully developed storms of about this type. It was prepared to form the basis of a strict mathematical computation on the theory of storms and to put to the test some of the assumptions that have been made by writers on the subject.

Starting from the center of the highs and also of the lows lying between them, every distance and angle formed by the direction of the wind as it crosses an isobar was measured, and the mean value thus found for 10 cases is incorporated on the chart. The storm is placed central in Illinois, in order to show both the contributing highs on the map of the United States, one of which covers the northern Rocky Mountain Plateau and the other the South Atlantic States. This is in general a favorite location, especially for a storm covering the central valleys, and the line joining the centers lies nearly along the middle of the high-pressure

[4] A question sometimes raised is, What is the distinction between primary and secondary cyclones? Going back to the definition given by Abercromby, who first described a secondary, it is quite evident that what he had in mind is not identical with what the Weather Bureau forecasters know as a secondary depression or cyclone, although both formations have some features in common. The chief points of difference are that Abercromby pictures the secondary as developing within the isobars of a primary and as being short-lived as a rule. He says: "Sometimes secondaries are persistent for a day or two, other times they are short lived, often lasting less than 12 hours, consequently they may not be observed on successive charts at 24 hours interval." The practice in this country conforms to that described but goes much farther and includes a large number of cyclones as secondaries that do not originate as described and figures by Abercromby. This is particularly true of cyclones advancing from the Pacific, the greater majority of which are recognized as secondaries, while the primary remains or disintegrates over the ocean. Practically all of the group known as Colorado lows or cyclones are secondaries in the view held at the U. S. Weather Bureau. Secondaries also develop over Texas and along the Gulf and the Atlantic coast south of Virginia and east of the Appalachians.

belt as it crosses the continent of North America. The other configuration frequently occurring is for the western high to be located as here shown, while the eastern high lies over New England and the Gulf of St. Lawrence, but in this case the upper portion of the isobars would not be shown, as the center would lie so far to the north that it would fall outside the region of observations.

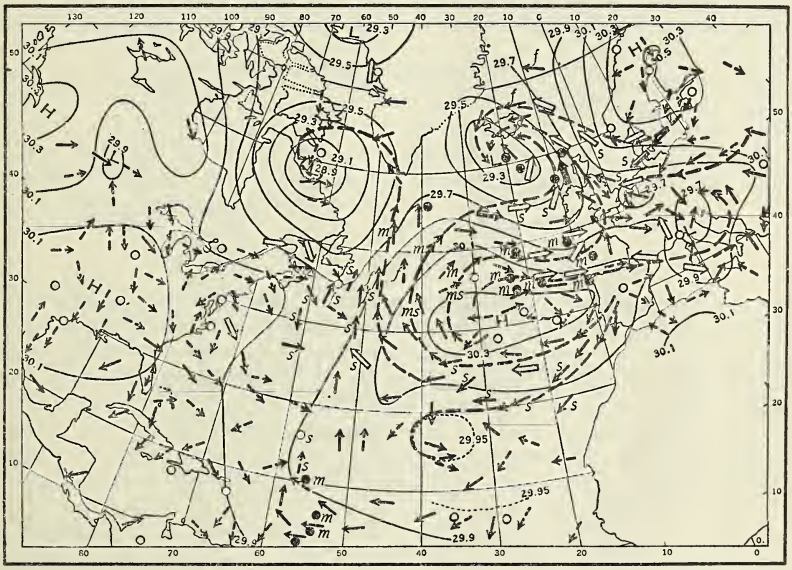
In order to facilitate the presentation of the facts, the following system was adopted: A line was drawn through the center of the low as nearly along the ends of the oval isobars as possible, and is the axis of reference; parallel to it is also drawn an axial line through the center of the high. Now a circle was placed near the center of the high and divided into 12 parts numbered 1 to 12, the count beginning at the southern end of the axis. Then a line was drawn from the points on the circle thus marked out from the high and the low, following the direction of the wind as shown on the maps, wherever this might lead over the intervening region. The points at which these wind lines, or stream lines of wind velocity crossed the several isobars were marked, and finally the whole chart adjusted to fit the actual measurements.

It is seen that on the western side of the high the lines 1 to 6 flow into the low, but from the eastern side only the lines 7 to 10; the lines 11 and 12 are probably lost in aimless drifting about, though the air thus unaccounted for must finally be drawn back into the circulation. The form of the wind lines flowing northwesterly is very different from those flowing southeasterly, the former spreading out over twice as wide an area as the latter. Likewise the velocity of the wind is less on one side than on the other—that is, 11 miles per hour in the westerly moving air and 14 miles in the easterly currents, the reckoning including all the lines indicated. The relative distance of the isobars from each other on any line shows the proportional velocity of the wind between them, where the isobars are close the velocity being greater on account of the increasing gradients of pressure. Thus in the chart the wind moves fastest in the region between 30.4 and 30.2, where it flows away from the high, and between 29.8 and 29.5, where it flows into the low. An examination of the angles at which the wind lines cross the isobars shows an important difference, viz, that the average angle is 60° for the winds blowing from the southeast and 48° for the winds coming from the northwest. The spreading out, lower velocity, and greater angle on the east side of the low, with concentrated lines, greater velocity and small angle on the west side of it, point to a distinct difference affecting the movements of the air in these two regions. The conclusion is that the winds blow from east to west much less easily than they do from west to east in this latitude and in the United States. Both these qualifications are required, because in this latitude the upper currents of air which are intimately associated with the highs and lows all move rapidly eastward in the upper strata, and hence winds blowing against them meet resistance; also in the United States the slope of the country is such from the Rocky Mountain Plateau to the Mississippi Valley that the wind, as it were, blows down hill and is impelled forward by gravitation. From these causes our northwest winds are violent and steady near the center of the low and the southeast winds are gentle.

The view of the wind circulation shown in Figure 4 is faulty since it assumes that the centers of the barometric formations are stationary, whereas every one knows that both are in motion. It remained for Shaw and Lempfert (*16*) to show the actual movement of the air with respect to the center of the cyclone.

As illustrating a new approach to methods of portraying the direction of the winds that are associated with traveling cyclones there are also presented Figures 5 and 6 as an illustration of the method followed by the authors named. These authors investigated the supply of air to the deep barometric depressions on the eastern border of the North Atlantic Ocean. They began with the principle that at any moment the flow of surface air is spirally outward from the periphery of a high-pressure area and spirally inward toward that of a low-pressure area, following Bigelow's conception. It seemed possible, therefore, that the northwest wind, for example, in a depression over the British Isles in winter might be comparatively warm if a short spiral curve connected it with an anticyclone over the Atlantic, but comparatively

cold if the spiral were elongated and the feeding anticyclone lay over Finland. In the progress of the investigation it developed that in the course of 24 hours the situation with regard to the spirals was entirely changed. The high-pressure and the low-pressure areas were no longer in the same positions, and it became apparent that although the spirals showed the direction of instantaneous motion of the air at any of the points in their length they would not represent the paths which the air actually followed unless the high and the low pressure areas remained stationary for some days, a combination of circumstances which practically never happens.



Direction and force of wind thus: ○ calm; → 1-3; ⟶ 4-6; ⇨ 7-8; ➡ 9-10; ➡ 11-12; the numbers refer to the Beaufort wind-scale
Weather is shown thus: ● rain; s showers; m mist; f fog

FIGURE 5.—Isobars, winds and weather noon G. M. T. November 15, 1882. Instantaneous stream lines of air between the high pressure areas and the low pressure areas are shown by the heavy dashed lines. (After Shaw and Lempfert)

The authors say (*16, p. 5*):

It is indeed evident, on consideration, that the curve on a synoptic chart which shows the wind direction at any point of its length is a hydrodynamical line of flow and does not show the path which a particle of air actually follows from day to day or from hour to hour unless the motion is steady and unchangeable, and that is notoriously not the case with the cyclonic depressions of the northern Atlantic.

The example reproduced in Figure 5 is the noon Greenwich mean time weather chart for November 15, 1882. The trajectories, plotted in dashed lines in Figure 6, are five in number and are described as follows:

Trajectory A. From a system of parallel isobars over Hudson Bay to a depression over the Adriatic.

Trajectory B. From the southern side of a very elongated anticyclone over Denmark and the Baltic, along the "col" connecting this anticyclone with the Atlantic high-pressure system, thence along the southeastern margin of the latter to a depression situated in mid-Atlantic.

Trajectory C. From an anticyclone over Russia, westward, to a depression over the English Channel.

Trajectory D. From the southwest of Ireland on a "col" between two anticyclones to a depression over the North Atlantic, south of Ireland.

Trajectory E. From the center of an anticyclone north of the Azores, northeastward, to the depression over the North Atlantic.

The longest trajectory (A) represents a steady flow of cold air from a west-northwest direction. It commences over Hudson Bay in a region of parallel isobars, on the southwest side of a depression over Greenland. If we follow the air in its flow southeastward, we find that it occupies a similar position with regard to a center of low pressure, on each of the three following days, so that the trajectory is approximately a straight line. Throughout this portion of its flow the pressure of the air was certainly not decreasing, and there appears even to have been a slight increase. The temperature was very low, only 15° to commence with, but the passage over the relatively warm ocean caused it to rise rapidly, and on November 16, when the Bay of Biscay was reached, a tempera-

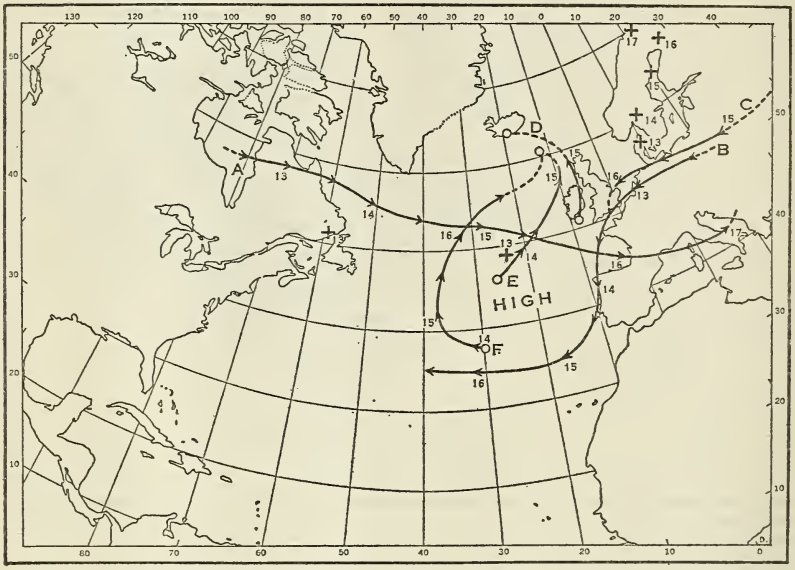


FIGURE 6.—Trajectories of air over the North Atlantic on November 15, 1882. Compare with the instantaneous streamlines shown in Figure 5. Crosses indicate the position of high pressure systems on the dates set opposite the crosses. The word HIGH indicates that the position of the center remained approximately constant. (After Shaw and Lempfert)

ture of 53° was attained. Subsequently the direction became more easterly, and on November 17 we find the air approaching a disturbance over the head of the Adriatic at a temperature of 55°. Simultaneously a decided diminution of its pressure took place.

Thus it is shown that the supply of air that comes within the circulation of the cyclone does not stand in that simple relation to the adjacent anticyclones indicated by Bigelow's chart of 30 years ago.

THE CHANGING DEMAND FOR WEATHER FORECASTS

The esteem in which any public service is held is most easily measured by the demand for it that arises with the passage of time. Measured by this yardstick, the forecast service of the Weather Bureau has gained both in reliability and in its wider application to the problems of commerce and agriculture.

The present demand as compared with that of some years ago is not so much to know that it will be colder, or warmer, as the case may be, but how much colder or warmer and when. In other words the demand is for greater detail and exactness and the expression of the forecasts in unequivocal terms. Fortunately the temperature lends itself to rather definite prediction both as to the amount of change and the time of its occurrence within rather narrow limits, as exemplified in the shippers' forecast, the fruit-frost forecast, and the cold-wave warnings.

The rain forecast three days in advance has its special application in orchard spraying as carried on in the apple districts of western New York. The special problem in this case is to forecast the occurrence of a spell of rainy weather three days in advance, so that the spray can be applied immediately before rain sets in. Since at least 36 hours are necessary to spray the larger orchards a knowledge of the coming of rain at least three days in advance is necessary. So, too, a knowledge of three or four days of clear weather is valuable in the harvesting of crops. In these cases an extension of the usual 24 to 36 hour forecasts is required.

FORECASTS FOR AVIATORS

The development of aviation has made the most pressing demand for detailed forecasts for short periods that has ever challenged the Federal weather service. The needs of aviation are separate and apart from the great majority of the interests served by the United States Weather Bureau and will require the closest sort of cooperation between the operator and the pilot on the one hand and the meteorologist on the other. Each of the several airways that are already established or to be established in the future must be considered as a distinct and separate unit so far as supplying flying data and forecasts is concerned.

The pilot wishes to know not only the existing weather conditions, but also those of the very near future along the air route at or near the time of his take-off. Since the network of meteorological stations that furnishes the observational material for the daily forecasts and warnings observes but twice in the 24 hours, the material thus supplied can be used only for the prediction of the general path of atmospheric disturbances that may cross or parallel the course of the airway. Thus there arises a necessity for setting up a line of meteorological stations along the air route, providing for communication between them and the control airport, day and night, and for making arrangements for digesting the material thus collected and communicating the results to the pilot in the form of forecasts and other advices that can be clearly understood.

All of this is an entirely new feature of weather forecasting that as yet is in its infancy.

MENTAL PROCESSES INVOLVED IN WEATHER FORECASTING

The question is sometimes asked, How are weather forecasts made? Quite recently the section of meteorology of the International Geodetic and Geophysical Union circularized its members with a view of discovering the scientific principles involved in the making of weather

forecasts as practiced by the forecast units of the various countries affiliated with the union. (See p. 12.)

Questions of this sort are easier asked than answered. Dealing first with the mental processes, it should be clearly understood that this is largely a personal attribute of the forecaster and that generalizations are not safe.

Every would-be forecaster is supposed to possess a working knowledge of the physics of the atmosphere, especially must he be able to place in the relation of cause and effect the physical processes common to the atmosphere and the sequence of weather events that flow therefrom. The novice during his apprenticeship must become thoroughly familiar with the behavior of cyclones and anticyclones at all seasons of the year, he must acquire the ability to distinguish between purely qualitative changes and those in which the magnitude of the change is the essential, as in determining when the wind speed may rise to gale force, etc. In a limited sense this problem has a geographic bearing. It is necessary to know, for example, the difference between forecasting for New England and Florida and between forecasts for the Pacific coast and for the Atlantic.

The philosophy of the forecaster is not greatly concerned with the reasons for making a certain forecast; indeed, speaking from personal experience, it would be necessary to recite the experience of many years to formulate the reasons for making the forecast for any particular map. There are two factors which militate against giving off-hand the underlying reason for any particular forecast. These are (1) lack of time and (2) intense concentration upon the details of the forecasts to be made rather than the consideration of the physical principles that may be involved.

Forecasters of the Weather Bureau, and for that matter probably in all other forecasting services, work at top speed because of the insistent pressure to get the earliest distribution of the forecasts.

The experienced forecaster on approaching any map is fortified in advance by a general knowledge of the barometric situation because of his knowledge of previous maps, and thus it happens that the writer, speaking for himself only, needs but a few moments to apprise himself of the important developments since the previous map. In complex cases a longer time might be required, but the point to be emphasized is that the impressions gained in the first minute or so of the examination suffice to form a conclusion (general, to be sure) as to the coming changes, and no amount of intense deliberation will materially improve on the conclusion arrived at on one's first careful inspection of the map.

Once the general situation is fixed in his mind, there remains but to dictate the details of the weather for the several geographic districts. During this period of dictation the utmost concentration on the subject in hand is required to secure and combine clarity and brevity; hence, as before intimated, the scientific aspect has small place in the mental processes of actual weather forecasting. The forecaster, working largely under empirical laws, strives to remain in full command of those laws rather than to think of their validity when tested in relation to well-established physical laws. In passing it may be remarked that rarely do weather forecasts contradict established physical principles.

METHODS OF ATTACKING THE PROBLEM

So far as known, there is no preferred way of acquiring a working knowledge of weather forecasting from synoptic maps, except that of learning through the school of experience. Skill can come only gradually and through much sustained practice. That being so, the Weather Bureau permits as many of its employees as may wish to make "practice" forecasts to do so and gives the practice forecasts the same verification that the official forecasts receive. Thus the younger employees of the bureau may compare their skill with that of the official forecaster.

In the next section a number of short series of consecutive daily weather maps are presented, together with the official forecasts made from each map of the series. The student should carefully examine the maps and endeavor to identify the reason for making the forecasts from the consecutive maps of the series. In some cases the reason or reasons will be apparent; in others they may be less clear. As perhaps throwing some light upon those of the second category, it may be remarked that the laws of chance apparently are operative in the occurrence of weather events. Statistics may be adduced that show the probability of some rain as against no rain, and one will find that the chance of no rain is ordinarily greater than that of a measureable amount falling on any given date.

Before attempting to make rain forecasts for any particular geographic district, the novice would do well to acquaint himself with the probability of rain as against fair weather. He may find that there are days with a measurable amount of rainfall at less than 10 per cent of the rainfall stations in the district. There may be other days when rain may fall at 10 to 30 per cent of the stations, and still other days, although much less frequent, when rain may fall at more than 50 per cent of the stations, and still more rare are those days with measureable rain at 95 to 100 per cent of the stations.

Obviously different forecasts are required according to the rain expectancy. The expression "generally fair" often used by forecasters may properly be used when rain is expected at not more than 5 per cent of the rainfall stations. "Local rains" means that rain is expected at a considerable number of rainfall stations in various parts of the district but not in each and every part of it. When a forecaster expects rain at more than 50 or 60 per cent of the stations in the district no qualifying terms are used.

From what has just been said it will be realized that the perfect rain forecast for each and every square mile of territory is not possible nor is it attempted under existing conditions.

READING SYNOPTIC CHARTS

The ability to read synoptic weather charts even in an elementary way is vital to an intelligent understanding and appreciation of the problems of the weather forecaster. Any treatment of the subject of weather forecasting which does not include the presentation and simple discussion of such charts is incomplete.

It is proposed here to present several short series of weather charts which are typical, not only of the ordinary, but also of the extra-

ordinary in the run of the charts. Since with two charts each day of the year the total number of charts considered by the forecaster in the course of a year is 730, and since no two charts are precisely alike, it is not possible to present more than a few typical series of maps, leaving it to the student who has more than a passing interest in the subject to supply himself with more abundant material from the published series of daily weather charts which may be had by placing a subscription with the Superintendent of Documents in Washington, D. C.

THE SERIES OF WEATHER CHARTS MARCH 3–6, 1908 (WINTER)

The first series of four charts, March 3–6, 1908, illustrates the development of a cyclone west of the Rockies, its crossing of those mountains, and subsequent increase in energy as it moved to the Great Lakes. Its passage thence down the St. Lawrence Valley was uneventful and is not illustrated by a chart.

The following is an explanation of the weather maps: Full lines are isobars; dashed lines, isotherms; and precipitation within last 24 hours is shown by vertical shading. The state of the weather at time of observation is indicated as follows: When the sky is clear there is an absence of shading in the small circle placed at the station. Cloudy sky is shown by full shading, partly cloudy by shading half of the circle, and the letters R and S when combined with the wind-direction arrows show that rain or snow is falling.

The striking quality of this series lies in the clear-cut movement across the continent in a little more than four days, a feat in itself not remarkable, but the widespread precipitation both as rain and snow from the Atlantic to the Pacific on several dates is out of the ordinary.

With most of the series of maps there is presented an abbreviated copy of the official forecasts issued from the eight forecast centers of the Weather Bureau operative in 1908, viz, Washington, D. C., Chicago, Ill., San Francisco, Calif., New Orleans, La., Denver, Colo., Portland, Oreg., Louisville, Ky., and Boston, Mass. The three last named were later merged with one or the other of those first named.

Some may wish to know the reasons which were back of the various forecasts for the dates given. The writer made the Washington, D. C., forecasts for the maps March 3–6, 1908, and can therefore indicate in a very general way the ideas that dominated in making the forecasts. As a very necessary preliminary some remarks on the qualifications of a weather forecaster from synoptic charts may be in order. A forecaster, like any other professional person, must be educated for the work, and by educated, a cursory leafing over of weather maps and the making of sundry mental reservations with respect to their significance is not meant, but rather that every would-be forecaster should serve an apprenticeship of not less than two or three years, the longer the better, (1) in acquiring a working knowledge of the subject, and (2) in a thorough and conscientious testing of the knowledge so acquired under conditions closely approximating those under which official forecasts are tested. The testing period is considered the most important of the two, since in no other way can the sound precepts be distinguished from the unsound. After all this is but the scientific way of securing results.

If an eminent physician be asked how he diagnosed a certain disease, his reply must be that the ability to diagnose disease grew out of his education and experience; in a somewhat similar way the forecaster will reply that his forecasts are dictated by education, training, and experience.

FIGURE 7.—WEATHER CHART, OF MARCH 3, 1908

The outstanding feature of this chart is the pressure distribution as shown by the isobars, there being 3 anticyclones in tandem, so to speak, along the northern border with zero (Fahrenheit) in the Province of Alberta, Canada, −20°, in western Ontario, and 60°, along the Gulf of Mexico, or a temperature difference in a north-south line of 80°. Snow was falling in Oregon, Montana, and other places, as indicated by the letter S on the chart. Rain, as indicated by the letter R, was falling in northern California, Southern Missouri, Arkansas, Oklahoma, and southeast Kansas.

The pressure distribution is typical of that which causes a Pacific cyclone after crossing the coast line to take a course to the southeast, because as may be noted, its course to the eastward is blocked by an anticyclone, 30.4 inches, over the Province of Alberta. Note also that there is a rather wide corridor of low pressure where there is little or no pressure gradient, from Washington and Oregon to the point marked LOW over western Colorado and northern Arizona. This particular pressure distribution clearly illustrates the general principle that cyclones move around the periphery of anticyclones rather than into them. When, however, the anticyclone is moving the following cyclone has the appearance of moving into the retreating anticyclone.

The wind circulation shown on this chart in the region around the center of the cyclone fails to approximate the ideal type of cyclonic circulation by reason of local orographic features common to the Rocky Mountain and Plateau regions. Note that the winds from the HIGH centered in the Lake region, or, more precisely, from its southwestern margin, are directed toward the center of the cyclone west of the Rockies and that precipitation is occurring in Arkansas, Missouri, and Oklahoma at the stations marked with an R, this being an example of rain spreading far to the east or east-southeast of a cyclone center.

In forecasting rain it is always important to consider the probable relative position of the HIGH and the LOW in the next 24 hours, especi-

ally when there is a probability of a flow of air from the one to the other as in the present case.

THE FORECASTS

The 24-hour changes, March 3 to 4, that have a bearing on the forecasts for March 4 were: A rise in pressure over western Canada, thus intensifying the HIGH north of Montana and roughly indicating a further movement in the next 24 hours; also a fall in pressure in southern California, that indicates the pressure situation in the area west of the Rockies will probably remain in the status quo. Colder weather was predicted in northeastern districts because of the eastward movement of the Lake region HIGH, and the exception of Maine was made because a substantial fall had already occurred in that State.

No precipitation was predicted for the Washington forecast district except in the case of Mississippi.

The detailed forecast follows, winds excepted because of lack of space.

Forecast till 8 p. m. March 4, 1908

New England: Fair to-night and Wednesday; colder to-night, except in Maine.

Eastern New York: Fair, colder to-night; Wednesday fair.

Eastern Pennsylvania, New Jersey, and Delaware: Fair and slightly colder to-night; Wednesday fair.

Maryland: Fair to-night and Wednesday; colder to-night in mountain districts.

District of Columbia: Fair to-night and Wednesday; temperature about freezing to-night.

Virginia: Fair to-night and Wednesday; colder to-night in southwestern portion.

North Carolina: Partly cloudy to-night and Wednesday; colder to-night on the south coast.

South Carolina and Georgia: Fair to-night; Wednesday increasing cloudiness.

Florida: Partly cloudy to-night and Wednesday.

Alabama: Partly cloudy to-night, slightly colder in east-central portion; Wednesday increasing cloudiness.

Mississippi: Local rains to-night or Wednesday.

West Virginia: Fair to-night; colder in mountain district; Wednesday partly cloudy.

West New York: Fair to-night and Wednesday; colder to-night in eastern portion.

West Pennsylvania: Fair to-night and Wednesday.

Ohio: Fair to-night; Wednesday increasing cloudiness.

Kentucky: Rain, warmer to-night; Wednesday rain.

Tennessee: Rain to-night, warmer in western portion; Wednesday rain.

Louisiana: Showers to-night and Wednesday.

Eastern Texas: Showers to-night and Wednesday.

Western Texas: Fair to-night; warmer in northwestern portion; Wednesday fair.

Oklahoma: Rain, warmer to-night; Wednesday showers.

Arkansas: Rain, warmer to-night and Wednesday.

Indiana and lower Michigan: Fair to-night and Wednesday.

Illinois: Showers in southern, fair in northern portion to-night and Wednesday.

Upper Michigan: Fair to-night; warmer in extreme northwestern portion; Wednesday fair.

Wisconsin: Fair to-night; warmer in northern portion; Wednesday fair.

Minnesota: Snow, with colder in northwestern portion to-night and Wednesday.

Missouri and Kansas: Showers to-night and Wednesday.

North Dakota, South Dakota, and Montana: Fair, colder to-night; Wednesday fair.

Colorado: Fair to-night; Wednesday snow; colder in eastern portion.

New Mexico: Fair to-night; Wednesday snow and colder in northern, fair in southern portion.

Arizona: Fair to-night; Wednesday rain or snow in northern, fair in southern portion.

Utah: Fair to-night; Wednesday snow.

Wyoming: Snow, colder to-night and Wednesday.

Eastern Oregon, eastern Washington, and Idaho: Fair, colder to-night; Wednesday fair.

Western Washington and western Oregon: Rain or snow to-night and Wednesday.

California: Showers in northern, except snow in foothills, fair in southern portion to-night; Wednesday fair.

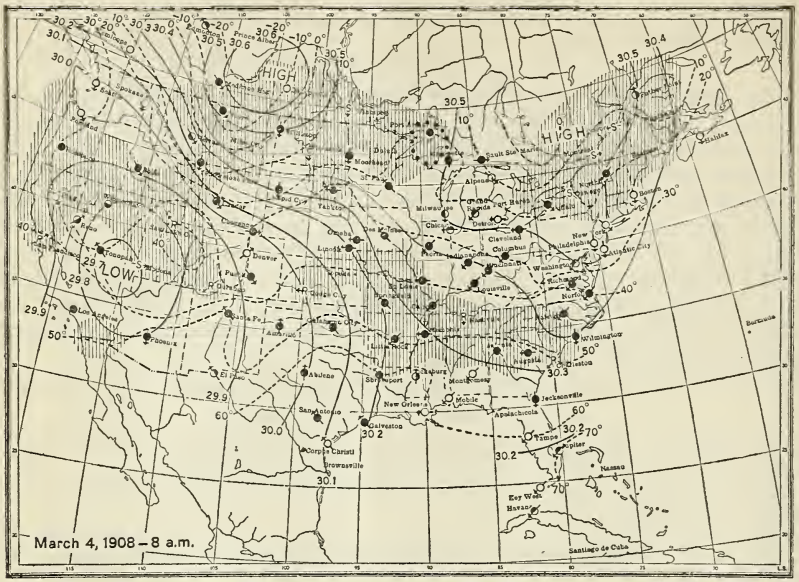


FIGURE 8.—WEATHER CHART, MARCH 4, 1908

The changes in the last 24 hours were an intensification of the Alberta anticyclone, central pressure therein having risen from 30.4 to 30.6 inches and temperature having fallen to −20° F.; the area of lower temperature has also spread to the southward into Montana and North Dakota. The cyclone center remains west of the mountains, with pressure about a tenth of an inch lower than on the 3d. The fact that the Alberta anticyclone has made some easting is favorable to a movement of the cyclone across the Rockies.

The precipitation over the eastern part of the country is due to a previous cyclone. On this map rain is falling in Kansas far to the east of the cyclone center, and it is also falling in western Colorado, Utah, and on the California coast.

Note also the great cloud blanket as indicated by shaded circles at observing stations over the east-central part of the country.

THE FORECASTS

The 24-hour changes, March 4 to 5, that have a bearing on the forecasts for the last-named date were an intensification of the HIGH north of Montana, which has now begun to influence the weather in the Dakotas and western Rocky Mountain districts, a general, though not pronounced pressure fall in California, the beginning of precipitation in California, Nevada, Utah, southwest Colorado and west Kansas, particularly the last since the pressure situation west of the Rockies has as yet given no indication of a movement of the Nevada LOW. No colder weather was predicted for any part of the Was' n forecast district, but higher temperatures were indicated for the lower Lake region and west Pennsylvania. The position of the LOW west of the Rockies is unfavorable to general and widespread rains, yet other conditions, the cloud blanket and the northeast winds, favored rain in the upper Ohio Valley and West Virginia. The detailed forecasts follow:

Forecast till 8 p. m. March 5, 1908

New England: Fair to-night and Thursday.

Eastern New York, eastern Pennsylvania, New Jersey, and Delaware: Fair to-night; Thursday increasing cloudiness.

District of Columbia and Maryland: Partly cloudy to-night and Thursday.

Virginia: Partly cloudy to-night and Thursday; probably rain in the extreme southern portion.

North Carolina and South Carolina: Local rains to-night and Thursday.

Georgia: Local rains to-night and on the coast Thursday.

Eastern Florida: Fair to-night and Thursday, except rain in extreme northeastern portion.

Western Florida, Alabama, and Mississippi: Partly cloudy to-night and Thursday.

Western New York: Fair to-night and Thursday; slightly warmer.

Western Pennsylvania: Partly cloudy to-night and Thursday; warmer to-night.

West Virginia and Ohio: Local rains or snows late to-night and on Thursday.

Kentucky and Tennessee: Partly cloudy with not much change in temperature to-night and Thursday.

Louisiana: Fair to-night and Thursday.

Eastern Texas: Fair tonight; Thursday showers in northern; fair in southern portion; colder in northwestern portion.

Western Texas: Rain and warmer in north, fair in southern portion to-night; Thursday, rain in north; fair in southern portion; colder.

Oklahoma: Rain to-night; Thursday rain and colder.

Arkansas: Rain to-night and Thursday; warmer to-night.

Indiana and Illinois: Showers in southern, fair in northern portion to-night and Thursday.

Michigan and Wisconsin: Fair to-night and Thursday.

Minnesota: Fair to-night, colder in western portion; Thursday fair.

Iowa and Nebraska: Rain or snow to-night and Thursday.

Missouri and Kansas: Showers to-night and Thursday.

North Dakota: Fair, colder to-night; Thursday fair.

South Dakota: Snow to-night and Thursday; colder tonight.

Montana: Fair to-night, colder in southeastern portion; Thursday fair.

Colorado: Rain or snow and colder to-night and Thursday.

New Mexico: Rain and colder in northern, fair in southern portion to-night; Thursday rain; colder in northern portion.

Arizona: Rain to-night and Thursday.

Utah: Rain or snow and colder in northern; fair in southern portion to-night; Thursday rain or snow, colder in northern portion.

Wyoming: Snow to-night and Thursday; colder.

Washington: Fair to-night, colder in eastern portion; Thursday fair.

Oregon: Fair to-night and Thursday.

Idaho: Fair in northern, snow in southern portion; colder to-night; Thursday fair.

California: Fair in north, showers in southern portion; cooler in southeast portion to-night; Thursday fair.

Nevada: Fair to-night; cooler in southern portion; Thursday fair.

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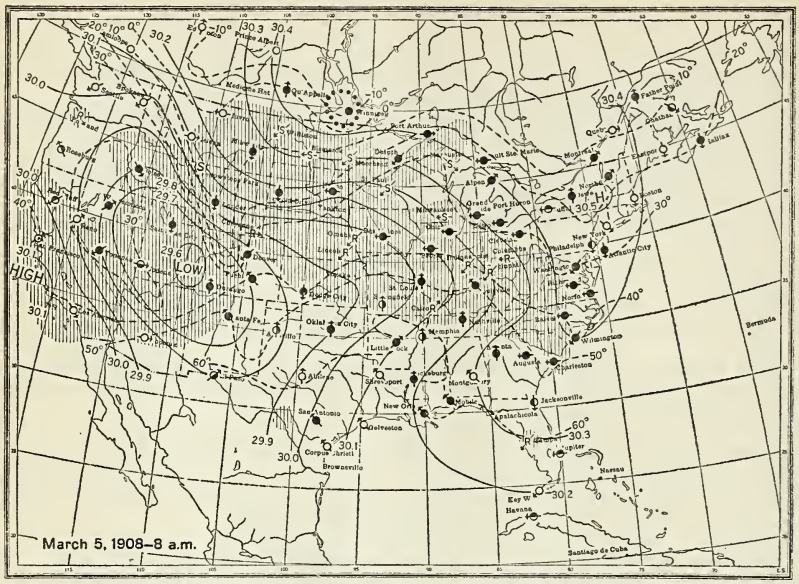

FIGURE 9.—WEATHER CHART, MARCH 5, 1908

The chief interest now centers on the position of the cyclone in the next 24 hours; its crossing of the Rockies is now clearly indicated by the curvature or bowing to the eastward of the isobars over the Plains States and the Ohio Valley and the very general fall in pressure to the eastward amounting to 0.2 inch in 12 hours.

Precipitation has already set in almost to the Atlantic. Temperature has risen in the Plains States, and thence eastward, and has fallen somewhat in Wyoming and Utah. The anticyclone along the northern border has advanced eastward and spread southward along the Atlantic coast. Snow is falling in Montana, the Dakotas, Minnesota, and parts of the Lake region. The great cloud blanket of the previous day is still in evidence, and a thrust of cold air from high latitudes is manifest by the southward bending of the isotherms over Colorado and Wyoming.

Precipitation has occurred during the previous 24 hours from the coast of North Carolina to the coast of California. The range of temperature on this map is from 60° F. in Florida to −10° in western Canada. The isotherm of 30° which, passing through Washington, D. C., bends northward to Marquette, Mich., passes southward to central Colorado and thence northwest to the Pacific coast in Washington.

THE FORECASTS

The 24-hour changes March 5 to 6 that had a bearing on the forecasts for March 6 were as follows: The eastward bowing of the isobars of 30.3, 30.2, 30.1, 30.0, and 29.9 inches along a line from southeast Kansas to southwest Virginia and the beginning of precipitation over the area of curvature of the isobars, clearly indicating that the LOW has already crossed the mountains, in the upper air at least. The forecasts are therefore for both rain and higher temperature and are as follows:

Forecasts till 8 p. m. March 6, 1908

New England: Fair, warmer to-night; Friday snow or rain.

Eastern New York: Snow in northern, rain in southern portion; warmer to-night and Friday.

Eastern Pennsylvania, New Jersey, and Delaware: Snow turning to rain, with warmer to-night and Friday.

District of Columbia, Maryland, and Virginia: Rain to-night and Friday; slightly warmer.

North Carolina: Partly cloudy and warmer to-night; probably rain. Friday, rain; warmer on the coast.

South Carolina, Georgia, and eastern Florida: Partly cloudy to-night and Friday.

Western Florida, Alabama, and Mississippi: Partly cloudy to-night and Friday.

Western New York: Snow to-night and Friday; slowly rising temperature.

Western Pennsylvania: Snow in northern, rain in southern portion to-night; slightly warmer; Friday rain and warmer.

West Virginia and Ohio: Rain to-night and Friday; slightly warmer.

Kentucky and Tennessee: Showers and continued warm to-night and Friday.

Louisiana: Fair to-night and Friday.

Eastern Texas: Fair to-night; Friday showers in northern, fair in southern portion; colder in northern and southwestern portions.

Western Texas: Rain in northern, fair in southern portion; colder in northern and southwestern portions to-night; Friday fair, colder.

Oklahoma: Rain to-night, colder in western portion; Friday rain, colder.

Arkansas: Rain to-night and Friday.

Indiana and Illinois: Showers to-night and Friday.

Lower Michigan, Wisconsin, Iowa, and Nebraska: Rain or snow to-night and Friday.

Upper Michigan: Snow, colder to-night; Friday snow, colder in eastern portion.

Minnesota: Snow to-night and Friday; colder to-night.

Missouri: Showers, with colder in northern portion to-night and Friday.

North Dakota and South Dakota: Snow to-night and Friday; colder to-night.

Kansas: Showers to-night and Friday.

Montana: Fair, colder to-night; Friday fair.

Wyoming: Snow to-night and Friday; colder to-night in southeastern portion.

Colorado: Rain or snow and colder to-night; Friday rain or snow; colder in southern portion.

New Mexico: Rain or snow and colder to-night; Friday fair and colder.

Arizona: Snow in northern, fair and colder in southern portion to-night; Friday fair.

Idaho: Rain or snow to-night or Friday; colder to-night.

Eastern Washington and eastern Oregon: Rain or snow to-night or Friday.

Western Washington and western Oregon: Fair to-night and Friday.

California: Frost warnings have been issued for California for Friday morning.

Nevada: Forecasts not received.

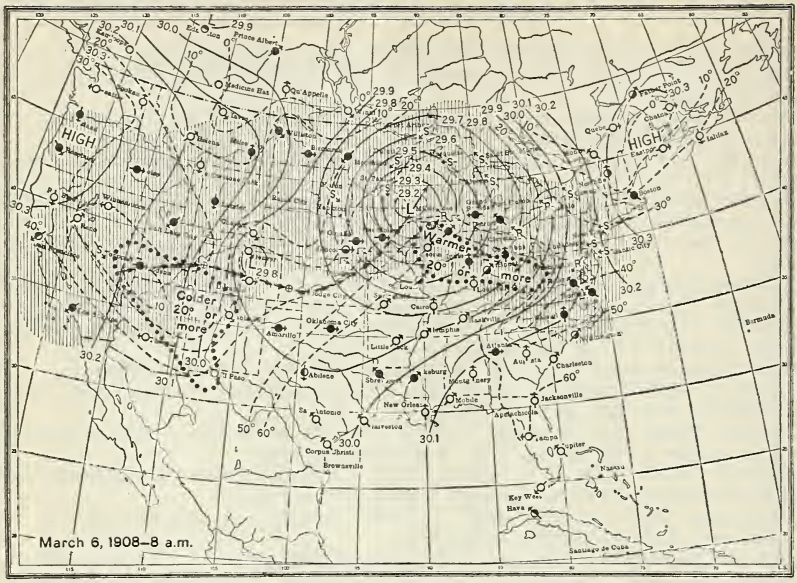

FIGURE 10.—WEATHER CHART, MARCH 6, 1908

Figure 10 is a weather chart which comes about as near to showing an idealized cyclone as any actual weather chart over land ever comes. Oceanic cyclones may have a more symmetrical flow of the air currents around the cyclone center, but the differences even then will be small. The distance between the center of the cyclone on the 5th and the center on the 6th, as scaled from the chart is 1,020 miles, or movement at an average rate of 43 miles per hour, yet the wind velocity in the center of the cyclone at anytime, was not over 15 miles per hour and the highest velocity recorded near the center was 34 miles per hour, at Chicago, Ill.; hence the conclusion based on many more cases, that the rate of progression of a cyclone across the country is not to be measured in miles per hour, as the speed of a railroad train is measured, but rather that its front develops faster or slower according to the character of the weather elements on its front. Of course an alternative view is always possible, viz, that the cyclone may move in the air streams 1 or 2 kilometers above the surface and thus satisfy the conditions for rapid movement.

In this case, the bowing of the isobars to the eastward along the fortieth parallel, the beginning of rain in the Ohio Valley, coupled with a substantial pressure fall, clearly indicated a rapid movement of the cyclone center.

The temperature distribution about the cyclone center on March 6 is typical of that which is associated with cyclonic centers in the cold season. Special attention is drawn to the isotherms of 40°, 50°, and 60°. Three days earlier the isotherm of 60° was confined to the Gulf coast. On the chart of the 6th it is within 40 miles of Chicago, and within the next 24 hours it will be on its way back to the Gulf. The cyclone continued its way down the St. Lawrence Valley during the succeeding 24 hours. The forecasts for the 7th are presented without discussion.

Forecast till 8 p. m. March 7, 1908

New England: Snow or rain and warmer to-night; Saturday rain in northern, fair in southern portion; warmer; storm warnings are displayed from Boston to Eastport.

Eastern New York: Rain and warmer to-night; Saturday clearing, colder in northwestern portion, warmer in southeastern portion; increasing south winds.

Eastern Pennsylvania, New Jersey, and Delaware: Rain this afternoon and probably to-night, warmer; Saturday fair and warmer; fresh, possibly brisk, south winds.

Maryland: Fair to-night, except rain in mountain districts; Saturday fair; warmer in eastern portion; fresh south winds.

District of Columbia: Partly cloudy and warmer to-night; Saturday fair and warmer.

Virginia: Fair to-night, warmer except in extreme southwestern portion; Saturday fair, warmer in eastern portion.

North Carolina and South Carolina: Fair and warmer to-night; Saturday fair, fresh southwest winds.

Georgia: Generally fair, except possibly a shower to-night or Saturday in northern portion; colder in northwestern portion Saturday, fresh southwest winds.

Florida: Fair to-night and Saturday; light to fresh south winds.

Alabama: Generally fair, except possibly a shower to-night or Saturday in northeastern portion, colder Saturday in northwestern portion; fresh southwest becoming northwest winds.

Mississippi: Fair to-night and Saturday; colder to-night in northwestern portion; colder Saturday; fresh south becoming northwest winds.

West Virginia: Fair and colder to-night and Saturday.

Western New York: Rain and warmer to-night; Saturday rain and colder.

Western Pennsylvania: Fair in southern, rain in northern portion; warmer to-night; Saturday partly cloudy, with rain or snow near Lake Erie.

Ohio: Fair to-night and Saturday, except rain or snow along the lake; colder to-night in southern portion; colder Saturday.

Kentucky: Thunderstorms and colder to-night; Saturday fair, colder.

Tennessee: Fair to-night, colder in western portion; Saturday fair, colder.

Louisiana: Fair to-night, colder in northern portion; Saturday fair, colder; fresh south to west winds on the coast.

East Texas: Fair, colder to-night and Saturday; fresh west to north winds on the coast.

Western Texas: Fair, colder to-night; Saturday fair; colder in eastern portion.

Oklahoma and Arkansas: Fair, colder to-night and Saturday.

Illinois and Missouri: Fair, colder to-night and Saturday.

Indiana: Fair, except snow near the lake; colder to-night and Saturday.

Lower Michigan: Snow to-night; Saturday snow, colder.

Upper Michigan: Snow, colder to-night; Saturday snow, colder in western portion.

Wisconsin: Snow in north, fair in south portion; colder to-night; Saturday fair; colder in eastern portion.

Minnesota: Fair, except snow in northeastern portion; colder to-night; Saturday fair.

Iowa: Fair, colder to-night; Saturday fair, colder in eastern portion.

North Dakota, South Dakota, Nebraska, and Kansas: Fair, colder to-night; Saturday fair.

Montana: Fair to-night and Saturday.

Wyoming: Fair to-night, colder in eastern portion; Saturday fair.

Colorado: Fair to-night, colder in central portion; Saturday fair.

New Mexico: Fair to-night, colder in eastern portion; Saturday fair.

Arizona and Utah: Fair to-night and Saturday.

Idaho: Fair to-night, colder in southern portion; Saturday fair.

Washington and Oregon: Fair to-night and Saturday; light frost to-night in western portion.

California and Nevada: Forecasts not received.

THE SERIES OF WEATHER CHARTS, JULY 30-AUGUST 1, 1909 (FLAT MAPS OF SUMMER)

(See also the text under the title "The rain forecast.")

FIGURE 11.—WEATHER CHART OF JULY 30, 1909

Next will be considered the reading of the weather charts of the summer—a time when the temperature contrast between the Equator and both poles is at its yearly minimum and as a consequence the general circulation reaches a period of relative quiet and local controls largely predominate. Weather forecasting now becomes at times a matter of picking the spots where showers and thunderstorms will occur.

Figures 11, 12, and 13 are charts for July 30–August 1, 1909. These charts are in strong contrast to those just discussed. The pressure and temperature gradients are weak, and naturally the movement of cyclones and anticyclones is at a minimum.

Pressure is highest over the south part of the north Atlantic, the Gulf of Mexico and the Pacific along the coast of Oregon and Washington—a normal summer pressure distribution whose chief features are high pressure over the oceans and low over land areas. The remnants of an anticyclone that was centered over northeast Wyoming on July 29 may be seen over northwest Wyoming (Yellowstone Park), southwest Minnesota, and eastern Colorado. Elsewhere pressure over the continent is close to 30 inches. In the northeast corner of the chart a cyclone is passing off to sea, and in the northwest corner a fresh cyclone is seen to be advancing across the northern part of the country. Widely scattered rains have fallen.

THE FORECASTS

In approaching for the first time the problem of weather forecasting in summer, the novice will be disappointed in discovering that many of the ideas gained from forecasting in cold weather are not applicable

to summer conditions. He will first observe that the summer barometric gradients are very light and that the movement of highs and lows is uncertain, halting, and difficult to anticipate and that the rainfall is distributed in a seemingly fortuitous way.

The weather conditions of July 29, 1909, may be seen by an inspection of Figure 11. As a result of the eastward movement of the Lake region low shown in that figure, temperature in New England and the Middle Atlantic States has risen, and a wide area of showers, as shown by the shading on the map of July 30, is in evidence.

Naturally the forecast for July 31 calls for lower temperature in those areas on the map inclosed by the isotherm of 80°.

Showers are forecast for the area south of the Pennsylvania-Maryland line and also in the South Atlantic and East Gulf States, although in the last-named for a different reason than in the region from southern Pennsylvania to the Carolinas. In the first-named region it was believed that the winds would become northerly, attended by showers and slightly lower temperature; in the Gulf region it was believed that the rains would be of convective origin and would continue, a belief that was not fully justified as may be seen from the shading on the map for July 30, 1909. The detailed forecasts follow. Attention is again called to the fact that the remarks on the forecasts apply only to the Washington forecast district.

Forecast till 8 p. m. July 31, 1909

New England: Fair to-night; cooler except in eastern Maine; Saturday fair, cooler.

Eastern New York: Fair to-night and Saturday, slightly cooler in the interior to-night.

Eastern Pennsylvania and New Jersey: Fair to-night and Saturday; slightly lower temperature to-night.

Delaware, District of Columbia, and Maryland: Showers this afternoon; partly cloudy to-night and Saturday; not much change in temperature.

Virginia: Unsettled, with showers to-night or Saturday.

North Carolina, South Carolina, Georgia, Alabama, Florida, and Mississippi: Showers to-night or Saturday.

Pennsylvania, West Virginia and Ohio: Fair to-night and Saturday.

Western New York: Fair to-night and Saturday; slightly cooler to-night.

Kentucky: Local thunderstorms to-night or Saturday.

Tennessee: Fair and continued warm to-night and Saturday.

Louisiana, Texas, Indiana, Illinois, Michigan, Wisconsin, Missouri, North Dakota, Nebraska, Kansas and Montana: Fair to-night and Saturday.

Minnesota: Fair to-night, warmer in northwestern portion; Saturday fair.

Iowa: Fair in western, showers to-night or Saturday in eastern portion.

South Dakota: Fair to-night, warmer in extreme eastern portion; Saturday fair.

Colorado, Utah and Wyoming: Fair to-night and Saturday.

New Mexico: Local showers to-night or Saturday.

Arizona, Fair in western, showers to-night or Saturday in eastern portion.

Washington, Oregon, California, Nevada, and Idaho: Fair to-night and Saturday.

FIGURE 12.—WEATHER CHART OF JULY 31, 1909

As compared with the pressure on the previous date, pressure on this date is everywhere, except in the northeast, a little lower both on the adjacent oceans and on the continent. In the warm season pressure occasionally rises or falls simultaneously over rather large areas, entirely apart from changes that are associated with cyclones and anticyclones. This fact is of considerable importance, especially in the attempt to relate terrestrial pressure changes to solar energy. Before it is concluded that there is a direct relation between changes in solar energy and terrestrial pressures, changes in the latter due to the movement of cyclones and anticyclones should first be eliminated, also the diurnal pressure wave that moves across the earth twice in 24 hours, and those accidental changes above mentioned. The amplitude of the latter runs from 0 to 0.10 and 0.12 inch.

The map of July 31 is a fair sample of the flat maps of summer. There is considerable cloudiness in the Lake region and thence south to the Gulf of Mexico. The barometric formations marked "high" and "low" are not true cyclones and anticyclones, for with the possible exception of the shallow depression over Missouri, they lack the wind circulation proper to these formations.

THE FORECAST FOR AUGUST 1

A rise in pressure over New England indicates that the Lake region "high" will probably advance in that general direction and possibly increase in intensity; therefore fair weather was forecast. The possibility of showers in the territory south of the Pennsylvania-Maryland border is apparent and is strengthened by a general decline in pressure over the great interior valleys and in a less degree over the South Atlantic States. A shower forecast was therefore put out, with the results partly disclosed by the shading on the map for August 1.

The pressure development on that map is significant of the changes that occur in the summer season and illustrates some of the difficulties of rain forecasting in summer. The map for August 2 (not reproduced) shows a fresh "low" coming in along the northern border and a clearing up or readjustment of the pressure situation in the central valleys.

Forecast till 8 p. m. August 1, 1909

New England: Fair to-night and Sunday.

Eastern New York, eastern Pennsylvania and New Jersey: Fair to-night and Sunday.

Delaware, District of Columbia, Maryland, Virginia and North Carolina: Partly cloudy, probably showers late to-night or Sunday; not much change in temperature.

South Carolina, Georgia, Florida, Alabama, and Mississippi: Thundershowers to-night or Sunday.

Western Pennsylvania, West Virginia and Ohio: Thundershowers to-night or Sunday; not much change in temperature.

Western New York: Fair to-night and Sunday.

Kentucky and Tennessee: Local thundershowers to-night and Sunday.

Louisiana: Fair, except showers in southeastern portion to-night or Sunday.

Texas, Oklahoma and Arkansas: Fair to-night and Sunday.

Indiana, Illinois, Michigan, Wisconsin and Missouri: Thundershowers to-night or Sunday.

Minnesota: Thundershowers in eastern, fair in western portion to-night; Sunday fair.

Iowa: Fair, except thundershowers in eastern portion to-night or Sunday.

North Dakota, South Dakota, Nebraska, Kansas, Montana, Colorado, Utah, and Wyoming: Fair to-night and Sunday.

New Mexico: Fair to-night, warmer in northern portion; Sunday fair.

Arizona: Fair, except local showers to-night or Sunday in northern portion.

Washington Oregon, Idaho, California, and Nevada: Fair to-night and Sunday; warmer in northern portion Nevada to-night.

FIGURE 13.—WEATHER CHART OF AUGUST 1, 1909

The important change in 24 hours shown on this chart is the rise in pressure in the Lake region from 29.9 to 30.1 inches. Apparently in sympathy with this rise, pressure has also risen quite generally over the interior valleys and New England, but it remains low, 29.9 inches from the middle Atlantic coast westward to the Great Plains. While the term "low" appears in six different places on the chart, the only real cyclonic depression is the one shown to the northwest of Montana. There is however, a great region of relatively low pressure westward from the Atlantic seaboard with the exception of New England to the Rocky Mountains. Vertical convection is favored by low pressure, and this whole region may be considered as favorable ground for the occurrence of showers and thunderstorms. The map of August 2 (not reproduced) shows two large areas of rainfall, one in the west extending from the Canadian border to the Mexican line about longitude 110° west, the other from the Texas coast to New Jersey.

The western rains, it is to be noted, occur in the rear of the cyclone rather than in its front, as in the East. Subsequent charts show a marked increase in pressure over New England where the pressure level on August 2 was 30.3 inches. Pressure over the Washington coast also rose to 30.2 inches. Whether the rise in both places was purely accidental or due to some common cause must be numbered among the unsolved problems of meteorology.

Forecast till 8 p. m. Monday, August 2, 1909

New England, eastern New York, eastern Pennsylvania: Fair to-night and Monday.

District of Columbia, Delaware, New Jersey, and Maryland: Unsettled to-night; Monday fair; moderate temperature.

Virginia: Partly cloudy; showers in southern portion to-night or Monday; moderate temperature.

North Carolina, South Carolina, Georgia, Florida, Alabama, and Mississippi: Thundershowers to-night or Monday.

Tennessee and Kentucky: Generally fair to-night and Monday.

West Virginia: Unsettled to-night, Monday fair.

Western New York, Ohio, and western Pennsylvania: Fair to-night and Monday.

Upper Michigan: Partly cloudy; thundershowers this afternoon or to-night; Monday fair.

Lower Michigan and Indiana: Generally fair to-night and Monday.

No forecasts for the remaining States were telegraphed to the central office, the day being a Sunday.

MISSED FORECASTS

If all of the weather charts were like those already presented and discussed, the work of a weather forecaster would be comparatively simple and generally satisfactory forecasts would be issued; on the contrary all weather charts are not simple, and the indications are not always clear-cut and easily read from the chart. There come to all forecasters at times conditions the outcome of which as expressed in terms of future weather, even 24-hours in advance, is extremely doubtful. In other words the forecaster does not know what the outcome will be with any degree of certainty, and he knows that he does not know. The best that can be done in such a situation is to predict that which seems the most probable under the circumstances and let it go at that.

The weak point of weather forecasting from synoptic charts always has been and doubtless will be in years to come an inability on occasions to correctly determine the exact course that will be pursued by the cyclone center during the ensuing 24 hours.

As the late H. A. Hazen (1849–1900) (*8*) once said: "We can hope to predict average conditions only." There are, of course, good and sufficient reasons why observations at the bottom of the ocean of air will not disclose what is happening at the level at which the energy of cyclones and anticyclones is to be found—about 2½ miles above the earth's surface. It is true that kite observations in the free air have been made for some years and telegraphed to the central Weather Bureau office, but the number of kite stations is but five, and not only are they widely scattered over the country but also at best afford data only at times when the weather permits kite flying. Pilot-balloon observations are being rapidly increased, but these afford information of the direction and speed of the wind only.

THE RAIN FORECAST

The rain forecast is next discussed in some detail. First are given some details that are helpful to a general understanding of the problem.

United States Weather Bureau forecasters make two forecasts each day; the first or morning forecast is issued about 9.30 a. m. and the second or night forecast is issued about 9.30 p. m., eastern standard time. The morning forecast covers the 24 hours beginning at 8 p. m. of the day of issue and ends at 8 p. m. of the next day, and thus is said to cover a period of 36 hours, counting from the time of issue. The night forecast is based on the observations made at 8 p. m. daily.

This forecast is the one usually carried by the morning papers and is for the two days immediately following its issue; as the morning papers usually phrase it, it is for to-day and to-morrow.

Rain forecasts are the most difficult of any which the forecaster is called upon to make, and for several reasons, chief among which is the fact that while the weather chart gives rather full information as to the horizontal motions of the surface air, the occurrence of precipition is predicated not so much upon horizontal as upon the vertical motion of the air. The weather chart supplies little or no specific information, nor can it, whether moist warm air will ascend to an altitude so great that the cooling by adiabatic expansion will condense a portion of its moisture as rain or snow.

One of the first facts that came out of a systematic study of weather charts was that the cyclone is associated with warm, moist, cloudy air near the surface which, by some means never very clearly understood, ascended and thus had a part of its moisture condensed as rain or snow and that, on the other hand, the anticyclone was just as definitely the representative of clear skies and cool, dry weather.

The knowledge thus empirically gained was used to predict rain, and in the great majority of cases it succeeded. Loomis and indeed later students have pointed out that not all cyclones are associated with rain, and it is now definitely established that rain or snow may occur when an anticyclone is the dominating control of the situation pictured on the weather chart.

CLASSIFICATION OF RAINFALL

Rainfall has been conveniently classed as cyclonic, convectional, and orographic. In each class warm, moist air must rise and expand under diminishing pressure, thus causing its temperature to sink to the point known as the dew point, or temperature at which some of its moisture will be condensed and may fall as rain or snow.

The cyclonic type.—It has long been held that in cyclones there must be a central up draught of warm, moist air; recent developments, however, have thrown doubt upon this belief. Nevertheless, the cyclonic circulation, whatever be the actual mechanical process whereby adiabatic cooling is brought about and moisture in the form of water vapor is condensed and falls as rain, must be considered as the chief cause of rain.

Convective rains.—These are based essentially upon the phenomenon of vertical convection.

Vertical convection in the atmosphere may be roughly described as the ascent of surface air that has been warmed by local surface heating, or it may be due to the descent of air from aloft that has been cooled to a temperature lower than that of its immediate environment. Its descent under that condition is due to gravity alone, but it causes surface air to rise. In the atmosphere the height to which heated air will ascend depends, largely, on the rate of decrease in temperature of the air with increase in altitude, sometimes spoken of as the vertical temperature gradient but latterly known as the "lapse" rate, or the rate of diminution of temperature with increase of altitude. In recent years, due to information collected from kite and sounding balloon flights, much more is known of the lapse rate than was the

case some years ago. It is known on purely physical grounds that air at the surface of the earth, if warmed above the temperature of its immediate surroundings will rise, but as soon as it reaches air of its own temperature further rising ceases; hence, there is a limit above which under ordinary conditions any locally warmed air will not pass. The lapse rate varies from day to day and even from hour to hour, according to season and the pressure distribution that prevails at the moment; in the cyclone for example, it is rather close to the critical value that leads to active convection because less warming is then necessary to initiate the process. This explains in part the cause of towering cumuli in cyclones and the thunderstorm type of rain due in the main to dynamical cooling in the atmosphere.

Convective rains in the United States are most common in Florida and the Gulf States. Early forecasters noticed and commented upon the difficulty of predicting rains in the Gulf States. Thus, Hazen (*8*) remarks:

> Rain on the Gulf coast does not follow any rules at all except that if it has begun seemingly in the centre of a fair condition one can not with safety predict anything but showers, and continue that prediction until the rain has ceased.

Convective rains of the Gulf States.—It is quite evident that for Florida and the Gulf States in general the rain forecast depends less on barometric formations than elsewhere in the United States, and this fact may be ascribed to several causes: (1) Low latitude and therefore small oscillations of atmospheric pressure; (2) proximity to an invariable supply of water vapor; and (3) relatively high temperatures and the direction of the prevailing winds. All of these conditions conduce to the creation of atmospheric instability and the precipitation of rain.

Rain, with or without thunder and lightning, occurs in summer in the Gulf region under at least three main conditions which may be tentatively classed as follows:

Many thunderstorms and showers (A rains) are due primarily to the eastward movement of a cyclonic storm or barometric depression along the northern border of the United States. Each of these storms, particularly the V-shaped depressions, have a troughlike extension of low pressure that reaches to the Gulf region, and thus active vertical convection becomes easy. Some rain may fall coincidently with the movement of the northern depression to the eastward of the central meridian of the region, but the bulk of the rain does not come until the center of the northern depression has reached the Gulf of St. Lawrence or even the Canadian maritime Provinces. Much also depends upon the level of the pressure in the trough which joins the Gulf region and the northern depression. The extent and magnitude of the anticyclone, if any, that follows the northern depression is also an important factor.

The B rains are those caused by the development of shallow barometric depressions, generally with a barometer level of about 30 inches. These rarely have a complete cyclonic circulation of the wind, but they cause very generous rainfall. An almost invariable accompaniment of this type is a wedge of higher pressure running in an east-west direction, or it may be an anticyclone with oval-shaped isobars.

(3) Finally, there are the C class rains, the convective showers and thunderstorms which occur in the southwest section of the western Atlantic anticyclone when it impinges upon southeastern United States, as shown in Figure 17. At such times the morning in the Gulf States may open with a cloudless sky, and although the pressure may be anywhere between 30 and 30.15 inches and the circulation anticyclonic the sky will cloud up in the afternoon and convective showers fall. On the other hand, an anticyclone which has come from the interior of the continent and sometimes drifts slowly southward after reaching the New Jersey coast and thus in a day or so simulates to a certain degree the pressure distribution above described, also gives rain in Georgia and Florida but not so far into the interior.

While, as already stated, the pressure is not so important in the rain forecast in the Gulf region as elsewhere, it can not be ignored. The Gulf States, being south of the parallel of 35° north latitude, come within the zone of high pressure that encircles the globe in the region 30° to 35° north latitude. As a matter of fact, pressure over the Gulf States in summer is far from being uniformly high or low but is slightly higher over Florida and Georgia than over the middle and western Gulf region, and the gradient over the last named is for southerly winds throughout the summer. Normal pressures, however, are seldom experienced; what we have to deal with in forecasting is a succession of up and down oscillations that are provided by the eastward drift of cyclonic systems along the northern border. The amplitude of these oscillations is not large, but it is sufficient to reduce the pressure level to 30 inches and slightly lower at times. Again, pressure may rise to 30.1 or 30.15 inches, and on rather rare occasions it may rise as high as 30.2 inches.

The higher pressure is due to the eastward drift of anticyclones that closely follow the paths pursued by cyclones along the Canadian border. The general trend of anticyclones being eastward with a more or less pronounced southerly component, it is found that after reaching the New Jersey coast, they spread southeastward over the ocean to reinforce the anticyclone normally over the western part of the north Atlantic, or they may drift more to the south along the Atlantic coast. When the oceanic anticyclone is reinforced, that fact is generally shown on Weather Bureau charts by a westward extension of the isobar of 30.1 inches over the southeastern United States, that isobar representing the outer margin of the oceanic anticyclone, a not unwarranted assumption. This isobar, and the one to the south of the center is meant, may extend west to the Texas coast before it begins to curve to the north and northeast. Since the winds on the south side of the anticyclone are from the east and southeast and thus moisture laden, rains are indicated in the east Gulf States even when the anticyclone prevails and pressure is as high as 30.2 inches. (Fig. 17.) Another case may be mentioned. When the advance of the northern anticyclone to the east is rapid, a pocket of low pressure may be left over Louisiana or Arkansas. This low pressure will be the locus of frequent showers, and it will pass to the eastward attended by a very weak cyclonic circulation.

In connection with the discussion of rains in the Gulf States, the weather charts of July 26–29, 1909, are next presented. These four charts cover the dates immediately preceding Figure 11, the weather chart for July 30, 1909, thus forming a consecutive series of seven summer charts. The indications from these charts are not at all clear and definite and we are again reminded of the late H. A. Hazen's precept for predicting rain in the Gulf States. (See p. 45.)

THE SERIES OF WEATHER CHARTS, JULY 26–29, 1909

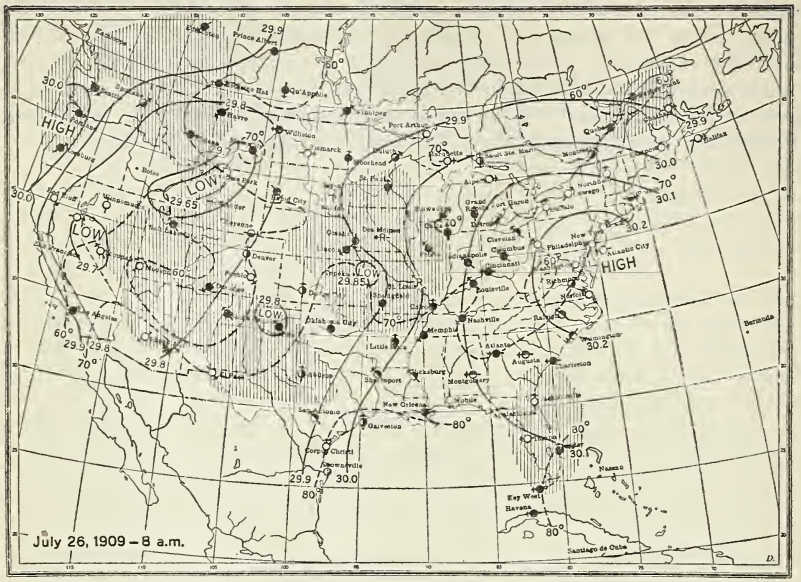

FIGURE 14.—WEATHER CHART OF JULY 26, 1909

On this date an anticyclone, 30.2 inches, has advanced from the Ohio Valley to the middle Atlantic coast and is passing off to sea. No rain has fallen in Atlantic Coast States within the last 24 hours, but rain is falling at a number of stations in the middle and upper Mississippi Valley. (See the places with the letter R affixed on the chart and the shaded area.) The latter indicates the region in which rains have fallen within the last 24 hours.

Note also the large area between the isobars of 29.8 and 29.9 inches where the absence of any isobar signifies that the pressure gradient is weak. It will also be noted that in this region two shallow depressions appear, the first in the Texas Panhandle and the second at Kansas City, Mo. Note also, and this is especially important, that the isobars of 29.9 and 30 inches are bowed toward the east in the vicinity of Kansas City, thus indicating a fall in pressure in that region. The forecasts follow.

Forecast till 8 p. m., July 27, 1909

New England: Fair to-night and Tuesday.

Eastern New York and New Jersey: Fair to-night; Tuesday unsettled; not much change in temperature.

Delaware, District of Columbia, Eastern Pennsylvania, Maryland, and Virginia: Increasing cloudiness to-night followed by unsettled weather and probably showers Tuesday; slightly warmer to-night.

North Carolina, South Carolina, and Georgia: Partly cloudy with showers to-night or Tuesday.

Eastern Florida: Partly cloudy to-night; Tuesday showers.

Western Florida, Alabama, and Mississippi: Partly cloudy with local showers to-night or Tuesday.

West Virginia: Increasing cloudiness, probably showers late to-night and Tuesday; warmer to-night.

Western Pennsylvania and Western New York: Increasing cloudiness; showers late to-night or Tuesday; not much change in temperature.

Ohio: Showers to-night and Tuesday.

Kentucky and Tennessee: Local showers to-night or Tuesday.

Louisiana: Fair, except showers in southeastern portion to-night or Tuesday.

Texas: Fair, except showers in northern portion to-night or Tuesday.

Oklahoma and Arkansas: Fair to-night and Tuesday.

Illinois: Thundershowers to-night and Tuesday.

Indiana, Wisconsin, Michigan, Minnesota, Iowa, Missouri, Nebraska, and Kansas: Showers to-night or Tuesday.

North Dakota: Showers to-night; Tuesday showers in eastern, fair in western portion.

South Dakota: Thundershowers to-night and Tuesday.

Montana: Showers to-night, cooler in southeastern portion; Tuesday showers in eastern, fair in western portion.

Wyoming: Local showers to-night or Tuesday; cooler.

Colorado and Utah: Local showers to-night or Tuesday.

New Mexico and Arizona: Fair, except showers in northern portion to-night or Tuesday.

Idaho: Fair in eastern and northern; thundershowers and cooler in southwestern portion to-night; Tuesday fair.

Washington and Oregon: Fair to-night and Tuesday; warmer Tuesday except near the coast.

90906°—30——4

HIGH
LOW
LOW
HIGH
Atlantic City
Bermuda
Nassau
Key West
Havana
Santiago de Cuba
Charleston
Jacksonville
Corpus Christi
Galveston
Port Arthur
Duluth
Minneapolis
St. Paul
Omaha
Lincoln
Kansas City
Little Rock
Memphis
Nashville
Chicago
Detroit
Buffalo
Pittsburg
Portland
San Francisco
Los Angeles
El Paso
Denver
Salt Lake
Winnipeg
Edmonton
Prince Albert
Medicine Hat
Swift Current
Qu'Appelle
Battleford
Prince Rupert
Kamloops
Calgary
Qu'Appelle
Havre
Helena
Spokane
Roseburg
Sacramento
Yuma
Tucson
Phoenix
Modena
Lander
Cheyenne
Pueblo
Amarillo
Abilene
Shreveport
Mobile
Montgomery
Atlanta
Knoxville
Louisville
Indianapolis
Cleveland
Toronto
Pittsburg
Scranton
Albany
Boston
Portland
Eastport
Halifax
Quebec
Montreal
Ottawa
Parry Sound
Port Arthur
Port Burwell
Grand Haven
Marquette
Duluth
Bismarck
Williston
Moorhead
Fargo
Huron
Pierre
Valentine
Dodge
Concordia
Wichita
Oklahoma
Fort Smith
Vicksburg
Meridian
Montgomery
Atlanta
Augusta
Charleston
Jacksonville
Key West
Havana
Nassau
Santiago de Cuba
Bermuda
Atlantic City
Washington
Baltimore
Philadelphia
Pittsburg
Cleveland
Toronto
Buffalo
Detroit
Chicago
Milwaukee
Duluth
Minneapolis
St. Paul
Omaha
Lincoln
Kansas City
Little Rock
Memphis
Nash

Minnesota: Thundershowers to-night or Wednesday.

Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas: Showers to-night and Wednesday.

Louisiana, Oklahoma, and Arkansas: Showers to-night or Wednesday.

Western Texas: Fair, except showers in northern portion to-night or Wednesday.

Eastern Texas: Fair to-night and Wednesday.

Colorado and Wyoming: Local showers to-night or Wednesday; warmer Wednesday.

New Mexico and Arizona: Fair to-night and Wednesday.

Utah: Fair, warmer to-night and Wednesday.

Idaho: Showers in northern portion, fair in southern to-night; Wednesday fair.

Washington and Oregon: Fair to-night and Wednesday.

California: Fair to-night; Wednesday fair, warmer in Sacramento and San Joaquin Valleys.

Nevada: Fair; warmer to-night and Wednesday.

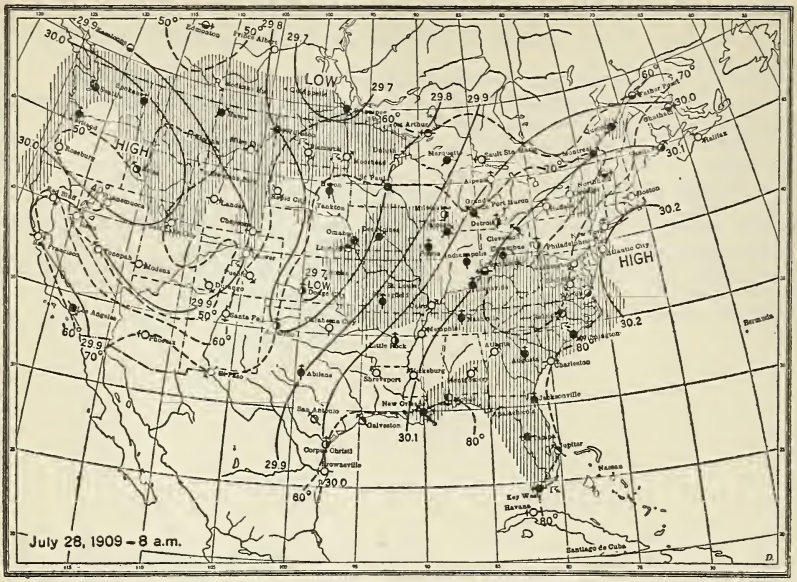

FIGURE 16.—WEATHER CHART OF JULY 28, 1909

A rise of a tenth of an inch in the pressure of the eastern anti cyclone is seen. It is perhaps not worth while to attempt an explanation of these temporary changes in level of cyclones and anticyclones, more than to say that a rise in pressure in an anticyclone is generally interpreted as an increase in energy, considering the pressure level as a criterion of energy, and a fall in the contrary manner. Pressure at Bermuda on this date was 30.3 inches, thus showing that the center was over the ocean and to the eastward of the continent. In the far West instead of two separate cyclone centers there is now but one of the well-known V shape. Rain has fallen over a large area, substantially from coast to coast—a rather unusual occurrence for a summer month. Compare with the charts of March 3–6, 1908. (Figs. 7–9.) The high pressure on both coasts is somewhat intensified on this map and is a rather unusual pressure distribution. The cloud blanket over the central valleys and the East is also exceptional. The text of the discussion on the maps of July 29–August 1 will be found on previous pages, where it was used to illustrate the flat maps of summer.

Forecast till 8 p. m., July 29, 1909

New England: Fair to-night and Thursday.

Eastern New York, eastern Pennsylvania and New Jersey: Fair to-night and Thursday; continued warm.

Delaware, District of Columbia, Maryland and Virginia: Fair to-night and Thursday; warmer to-night.

North Carolina, South Carolina, Georgia and Florida: Partly cloudy with local showers to-night or Thursday.

Alabama and Mississippi: Partly cloudy with showers near the coast to-night or Thursday.

West Virginia and Ohio: Partly cloudy with showers to-night or Thursday; warmer to-night.

West Pennsylvania and western New York: Partly cloudy with showers to-night or Thursday; continued warm.

Kentucky and Tennessee: Showers to-night or Thursday.

Indiana, Illinois, Michigan, Wisconsin and Missouri: Thundershowers to-night or Thursday.

Minnesota: Showers to-night; Thursday showers in eastern portion; fair in western.

Iowa: Showers to-night; Thursday fair.

North Dakota: Showers to-night and Thursday.

South Dakota: Fair to-night: colder in eastern portion; Thursday fair.

Nebraska: Showers in eastern, fair in western portion to-night; Thursday fair.

Kansas: Fair to-night and Thursday.

Montana: Showers to-night or Thursday.

Louisiana, Texas, Oklahoma, Arkansas, Colorado, New Mexico and Wyoming: fair to-night and Thursday.

Arizona and Utah: Fair; warmer to-night; Thursday fair.

Idaho: Fair to-night; Thursday fair, warmer.

Washington: Fair to-night; Thursday fair; warmer in interior.

Oregon: Fair to-night; warmer in southwestern portion, except the coast; Thursday fair.

California: Fair to-night; warmer in the San Joaquin Valley; Thursday fair.

Nevada: Fair; warmer to-night and Thursday.

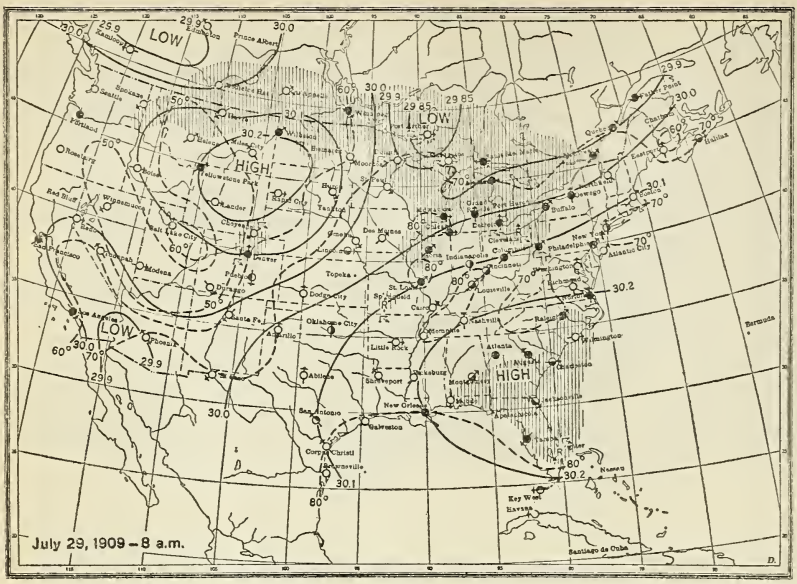

FIGURE 17.—WEATHER CHART OF JULY 29, 1909

This chart shows a fresh anticyclone in the far Northwest, and the eastern anticyclone is now in its fourth day of development, having spread to the south so that it now overlies Florida and the East Gulf States. The center is still at Bermuda, 30.32 inches, and there is an extension to the southwestward; note the course of the isobar of 30.2 inches, and particularly the area of rainfall entirely within the isobar just mentioned. This rain, the record shows, was predicted on the previous morning. The point illustrated is that it is necessary, at times to depart from the fundamental proposition which associates an anticyclone with fair weather. From the foregoing it may be learned that the production of rain or snow is one of nature's ways of adjusting inequalities in the temperature distribution in the free air. A mass of warm, moist air is made to rise; it expands and cools, and by its doing so rain or snow is precipitated. The original air mass has changed its state; it is now dry and cooler than it was originally, and in that condition it mixes with other air only to perform again the same cycle of change.

In the last 50-odd years forecasters have learned not to cling to the cyclone as the sole rain producer but to study the anticyclone and especially the relative geographic position of the two formations.

In a former discussion (*9, p. 111–112*) the following precept was formulated: "When the anticyclone is northeast of the cyclone, the tendency to unsettled weather between them with rain or snow is at a maximum." The principle back of this precept is rather simple. The wind circulation proper to the southwest sector of the anticyclone is manifest in a flow of relatively cold air toward the distant cyclone center which flow, according to the Bergen school, serves as an inclined plane up which the warm air of the cyclone ascends. Precipitation naturally results.

In this precept it is the relative position of the two formations that counts; the anticyclone must be to the north or northeast of the cyclone; reverse the positions and nothing happens. The convergence of air in the cyclone also spells precipitation. Divergence on the other hand results in failure of the rains.

Forecast till 8 p. m. July 30, 1909

New England: Fair, except showers in northwestern portion to-night; Friday fair.

Eastern New York: Fair in southern, thunderstorms in northern portion to-night and Friday; warmer in extreme southern portion to-night.

Eastern Pennsylvania and New Jersey: Fair and continued warm to-night and Friday.

Delaware, District of Columbia, Maryland, and Virginia: Partly cloudy and continued warm to-night and Friday.

Eastern North Carolina: Fair to-night and Friday.

South Carolina, eastern Florida, and Georgia: Local showers to-night or Friday.

Western Florida, Alabama, and Mississippi: Fair to-night and Friday; continued warm.

West Virginia, western Pennsylvania, western New York, and Ohio: Thundershowers to-night or Friday; continued warm.

Kentucky and Tennessee: Fair, continued warm to-night and Friday.

Louisiana: Fair, except showers in southeastern portion to-night or Friday.

Texas: Fair to-night and Friday.

Oklahoma and Arkansas: Fair to-night; cooler in northern portion; Friday fair.

Indiana, Illinois, and lower Michigan: Fair, cooler to-night; Friday fair.

Upper Michigan: Showers, cooler to-night; Friday fair.

Wisconsin, Iowa, and Missouri: Fair, cooler to-night; Friday fair, cooler in eastern portion.

Minnesota: Fair to-night; cooler in eastern portion; Friday fair.

North Dakota: Fair to-night; Friday fair, warmer.

South Dakota: Fair to-night; Friday fair, warmer in western portion.

Nebraska: Fair to-night; cooler in eastern portion; Friday fair.

Kansas: Fair, cooler to-night; Friday fair.

Montana: Fair, warmer to-night and Friday.

Colorado: Showers in eastern, fair in western portion to-night and Friday.

New Mexico: Fair, except local showers in eastern portion to-night or Friday.

Arizona and Utah: Fair to-night and Friday.

Wyoming: Fair, warmer, except showers and cooler in southeastern portion to-night; Friday fair, warmer.

Washington and Oregon: Fair to-night; warmer in eastern portion; Friday fair.

Idaho: Fair, warmer to-night; Friday fair.

California: Fair to-night and Friday; cooler Friday in Sacramento and San Joaquin Valleys.

Nevada: Fair to-night and Friday; warmer in northern portion.

ARIZONA AND NEW MEXICO TYPE OF PRECIPITATION

Perhaps the most striking illustration of the capabilities of anticyclonic circulation in causing extensive rains is found in the semiarid region of southwestern United States—Arizona and New Mexico and parts of southern Utah and Colorado. It may be remembered that in those States and parts of States there is a rather pronounced rain maximum in the summer months—July and August and the first part of September. This rainy season is much more pronounced in some years than in others; nevertheless it stands out in the precipitation normals deduced from at least 50 years of record. The normal precipitation of Santa Fe, N. Mex. (Table 1) will illustrate the matter:

TABLE 1.—*Normal monthly precipitation in inches, Santa Fe, N. Mex.*

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.59	0.84	0.73	0.86	1.11	1.04	2.71	2.36	1.64	1.07	0.78	0.76

In July the highest temperature in continental United States and uniformly low pressure are encountered in the lower Colorado River Valley. This low pressure is sometimes called the Gulf of California semipermanent LOW; it is centered a little to the south of Yuma, Ariz. The rainfall at that station averages about 3 inches a year, an amount that is considerably exceeded in the month of July alone at some of the higher elevations of Arizona in a single day.

Summer rains in Arizona and New Mexico begin with a shallow barometric depression that passes across Arizona, the pressure fall in which is slight and is scarcely observable on the charts since the general contour of the isobars is rarely changed. At that time of year pressure over the entire middle and southern plateau, sometimes to the Canadian border, is low. These rains are mostly of convective origin, in the beginning at least. As the northern end of the trough of low pressure passes, say to the eastward of Idaho, an offshoot of the high pressure system of the Pacific passes inland; or it may be that an anticyclone moves southeastward from British Columbia. As soon as the eastern front of the anticyclone reaches Wyoming or western South Dakota, the peak of the shower period in Arizona and New Mexico is reached. The term "peak" is used to indicate rain at more than 40 per cent of all the rainfall stations in those States; during some peaks as many as 70 to 80 per cent and in an extreme case to 95 per cent of the rainfall stations in the State reported rain. At times, when pressure distribution is favorable, a continuous shower period ensues, ranging in length from three days to two weeks. In July, 1921, two rainy spells succeeded each other, thus prolonging the rainy spell for practically half a month. Rain may fall at the elevated stations on consecutive days for the greater part of a month; thus, at Chlarsons Mill, Arizona, altitude 8,000 feet, rain fell on 30 days in July, 1914, and the total for the month was but 6.45 inches, the daily amounts being small. In the same month Alpine, Ariz., altitude 7,939 feet, had rain on 25 days, mostly consecutive. Much of this rain comes in the form of afternoon thunderstorms, sometimes with hail on the high plateaus.

An anticyclone or ridge of high pressure, whatever form it assumes, as it spreads eastward from the Pacific over Washington and Oregon will be attended by air currents from the northeast or east on its southern margin, and these currents will cause orographic rains on the eastern slope of the mountains. The speed of these air currents is somewhat accelerated by the presence of the semipermanent LOW pressure over the lower Colorado River Valley.

The relative position of the two formations, the anticyclone over, say, western South Dakota and the cyclone, or, more properly speaking, the depression of the barometer over or near to Yuma, Ariz., is conducive to precipitation in Colorado, southeast Utah, Arizona, New Mexico, and extreme southern California.

THE SERIES OF WEATHER CHARTS, JULY 2-3, 1914

FIGURE 18.—WEATHER CHART OF JULY 2, 1914

Two sets of weather charts typical of summer conditions favorable to generous precipitation in Arizona and New Mexico are presented, viz, for the dates July 2–3, 1914 (figs. 18 and 19), and July 12–18, 1919. (Figs. 20–26.) These charts may be said to represent the two extremes of pressure distribution favorable to precipitation in the Southwest. The 1914 charts are characterized by very light pressure gradients over the Great Basin and plateau regions and thus are more nearly normal for the season than is the second set. The latter really present an abnormal pressure distribution for July, since pressures of 30.3 inches in July rarely occur along the Washington and Oregon coasts.

In a way, however, there is some similarity between the two sets of charts. Compare, for example, the chart for July 3, 1914 (fig. 19), with that of July 17, 1919. (Fig. 25.) In both there

is a shallow anticyclone to the northeast of Arizona. The relative geographical position of the high pressure with respect to the low seems to be the key to the occurrence of generous rains in the States under consideratio .

On July 3, 1914, showers fell at 75 per cent of the rainfall stations in Arizona, 78 per cent of those in Colorado, and 64 per cent of those in New Mexico.

On July 17, 1919, rain fell at 79 per cent of the rainfall stations of Arizona, 30 per cent of those in Colorado, and 63 per cent of those in New Mexico, so that with the exception of Colorado in 1919, the conditions shown in the two maps, that for July 2, 1914, and that for July 17, 1919, were about equally effective as rain producers.

FIGURE 19.—WEATHER CHART OF JULY 3, 1914

By extending the July, 1919, set of charts so as to include the days from July 12 to July 18, 1919, a remarkable period of showers in the Southwest comes to light.

For each day of this period the percentage of the rainfall stations of Arizona, Colorado, and New Mexico at which a measurable amount of rain was recorded, including traces, has been computed. The total number of rainfall stations in each of the States named was Arizona, 99; Colorado, 126; and New Mexico, 158.

The percentages given in Table 2 show the distribution of the rainfall for the dates given; they also show that the peak of the shower period was reached on different dates; thus, for Arizona, it was reached on July 15; in Colorado, on July 14; and, in New Mexico, on July 14 and 15, the percentages of the two dates being substantially equal; therefore the ideal pressure distribution for generous and widespread rains in New Mexico, for example, is illustrated by the

weather charts of July 13–14, 1919. Similarly the ideal distribution for the remaining States may be seen by a simple inspection of Table 2.

TABLE 2.—*Percentage of rainfall stations in Arizona, Colorado, and New Mexico having a measurable amount of rain on July 12–18, 1919*

State	July 12	July 13	July 14	July 15	July 16	July 17	July 18
Arizona	68	66	73	83	73	79	59
Colorado	47	59	64	49	39	30	56
New Mexico	36	55	84	83	72	63	49

In order to preserve the continuity of the discussion the weather charts for July 12–18 will be individually treated.

THE SERIES OF WEATHER CHARTS, JULY 12–18, 1919

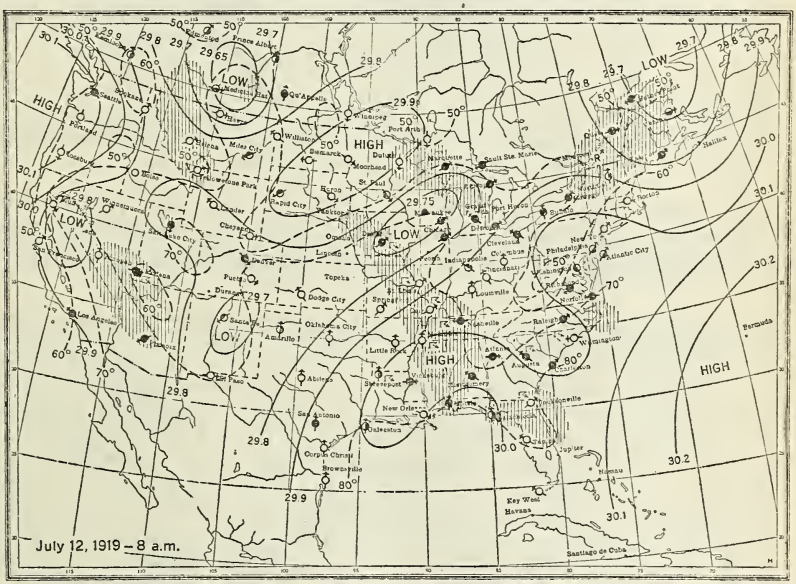

FIGURE 20.—WEATHER CHART OF JULY 12, 1919

Pressure west of the Rockies with the exception of the coastal regions of Washington and Oregon is low, and morning temperatures are fairly high. Thunderstorms already have occurred in Arizona, southwest Utah, and southeast Nevada. The temperature contrasts in a north-south direction are favorable to a continuation of showers and thunderstorms.

FIGURE 21.—WEATHER CHART OF JULY 13, 1919

This chart shows a spreading inland of the high pressure over Washington and Oregon coasts. The temperature over the southern plateau continues high and the area of thunderstorms during the last 24 hours has been enlarged.

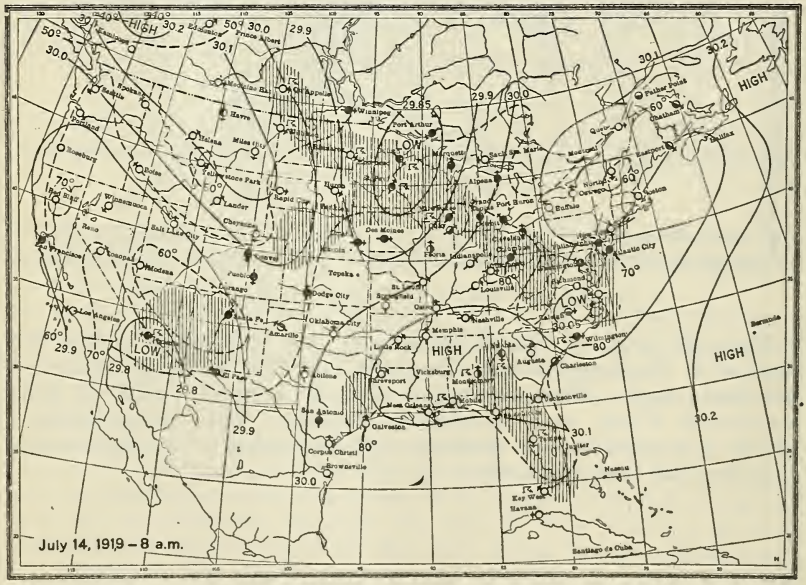

FIGURE 22.—WEATHER CHART OF JULY 14, 1919

The important feature of this chart is the southeastward extension of high pressure, as shown by the isobars of 30, 30.1 and 30.2 inches.

Rain fell at 65 out of the 98 rainfall stations in Arizona and at 135 out of 158 rainfall stations in New Mexico, thus illustrating the very great efficiency of rising pressure to the northward as a rain producer in the semiarid Southwest.

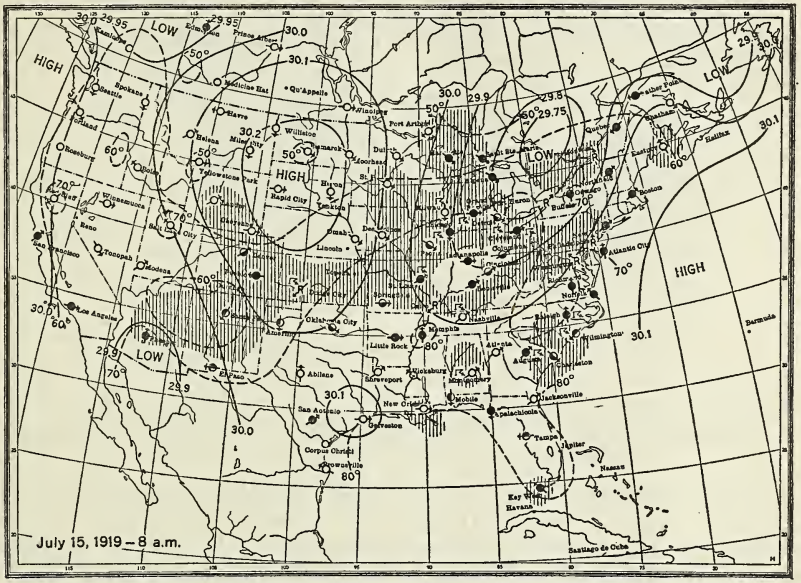

FIGURE 23.—WEATHER CHART OF JULY 15, 1919

This chart differs from those immediately preceding in that the oceanic anticyclone is now over the continent and in a position conducive to rains in the Southwest. While its position as shown by the chart is but momentary, its influence is exerted continually until it recedes beyond the geographical limits in which it is effective as a rain producer for Arizona and New Mexico. The peak of the rains in Arizona occurred on July 15, with 83 per cent of the stations reporting rainfall. The chart of July 14 may therefore be considered as the ideal one for predicting rains for that State. New Mexico also had many rains regardless of the differences in longitude.

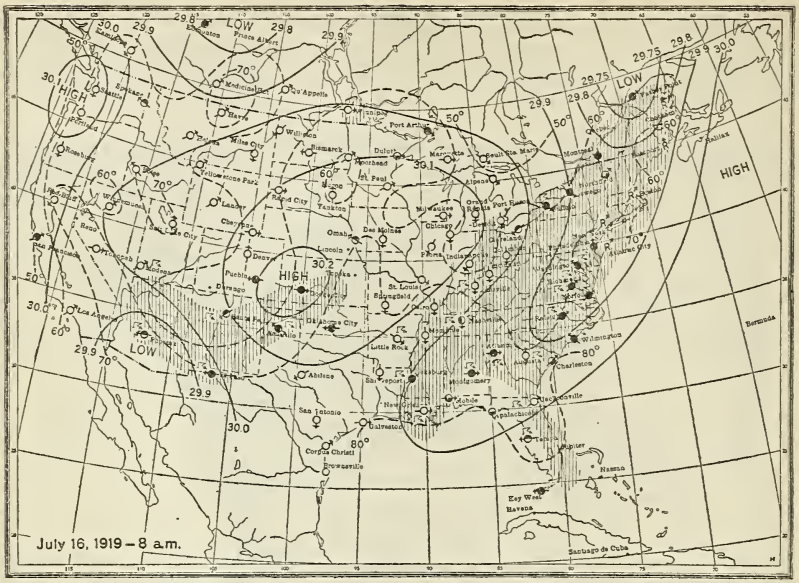

FIGURE 24.—WEATHER CHART OF JULY 16, 1919

On this chart the center of the anticyclone has advanced to the southward over western Kansas and eastern Colorado. A fresh cyclonic storm is showing in the extreme northwest corner of the chart; whence it may be inferred that a second period of showers is approaching; subsequent charts show that inference to be well grounded.

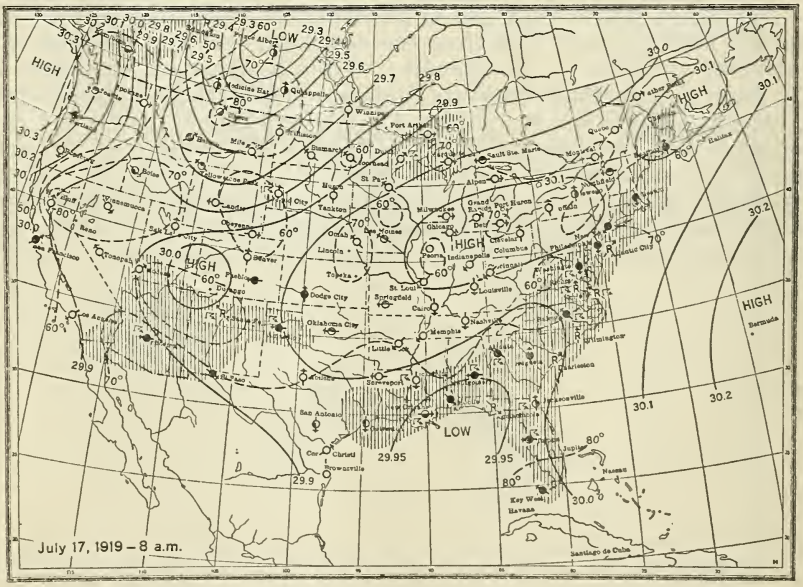

FIGURE 25.—WEATHER CHART OF JULY 17, 1919

This is a rather unusual chart for July, unusual in the sense that it is more like a winter than a summer chart. The northern depression

has central pressure down to 29.3 inches and the Pacific anticyclone a pressure of 30.3 inches; thus there is a difference of a whole inch in the pressure between the two formations and correspondingly steep gradients for summer. This is exceptional, as is the length of the shower period in Arizona and New Mexico.

FIGURE 26.—WEATHER CHART OF JULY 18, 1919

The inland spread of the Pacific anticyclone is shown by the course of the isobar of 29.9 inches, which has advanced nearly to the Dakotas, attended by a pronounced fall in surface temperature.

THE RAIN FORECAST IN NORTHERN DISTRICTS WEST OF THE GREAT LAKES

The majority of the cyclones that enter the continent from the Pacific cross to the Atlantic in the vicinity of the parallel of 50° north latitude or, as is sometimes stated, along the northern circuit. On the other hand in the cold season the presence of vigorous anticyclones over western Canada may deflect the path of the cyclone to the southeast across the plateau and Rocky Mountain region to the neighborhood of the Gulf of Mexico. Arriving in the vicinity of that region, the cyclone generally recurves to the northeast and eventually passes down the St. Lawrence Valley; hence the often heard expression "Regardless of where the cyclone enters the continent it will pass out via the St. Lawrence Valley." As a matter of fact many cyclones do not survive the crossing of the continent, and others pass into the Atlantic south of the St. Lawrence Valley.

The problem of forecasting rain on the appearance of a cyclone in the Northwest is not easy. Professor Cox (*9, p. 299, 301*), commenting on the subject, says:

> That precipitation occurs in advance of a LOW with clearing or fair weather following in its rear was once accepted as a general precept. However, in the

Chicago district a considerable proportion of the recorded precipitation occurs on the west and north sides of a LOW or a trough of low pressure, when the weather to the east and southeast of the trough is clear, with accompanying high temperatures; and the unsettled conditions are found on the "break" and to the northwest, that is, where the temperature is falling and the winds are shifting to northerly and possibly northeasterly; in other words, on the northwest side of a trough, assuming that it trends northeast-southwest. * * *

It is comparatively easy to estimate in advance the area that will be covered by precipitation in connection with an approaching low or trough when the precipitation has already started on the east side of the low, but the difficulty in the Chicago forecast district is that the disturbances are usually dry as they approach the western limits of the district, and the forecaster must face the problem of locating the sections in which rainfall will first appear. If the pressure in the trough of the depression is as low as 29.70 inches at Omaha, it is seldom that the depression gets by the eastern Iowa stations without causing precipitation, except during dry periods.

East of the Great Lakes the problem is not so much whether or not precipitation will occur, as to how far south it will extend. No invariable rule can be given; reliance must in general be placed upon the general pressure situation over eastern United States.

SNOW, SLEET, OR ICE-STORM FORECAST

Heavy-snow forecasts are among those of major importance in the northeastern part of the United States, especially in the great cities of the Atlantic seaboard. New York City, for example, maintains a snow-removal organization that undertakes the removal of snow from several hundred miles of city streets. A forecast of heavy snow at least 12 hours in advance is essential to the successful functioning of this organization.

Heavy snow is most frequently recorded in the New England and Middle Atlantic States, although it is also, but less frequently, recorded in the Ohio Valley and the Lake region. Heavy snow occasionally occurs in the middle Rocky Mountain region in late spring; its removal at that season, however, is not a serious problem.

The type of pressure distribution that gives rise to heavy snow is a cyclonic storm moving from lower to higher latitudes in the cold season when the path of the cyclonic storm is apparently blocked by an anticyclone or other pressure formation that will induce cold surface air currents to move toward and into a region of higher temperature and air of high moisture content. The surface temperature should be close to freezing. Frankenfield (*9, p. 255*) says, "Other conditions being favorable, snowfall will probably be heaviest when temperatures are between 24° and 30°."

A series of four weather charts, February 10–13, 1899 (figs. 27–30), is presented below as typifying the weather conditions associated with heavy snow and rather extreme cold. These charts represent the February, 1899, "near blizzard" in the Middle Atlantic and New England States, when snow fell from the Carolinas to New England, the depths being greatest in Virginia, Maryland, and the District of Columbia. The snow was badly drifted by the high winds of the storm, and transportation was generally disorganized.

These charts show, first, the progress of a great anticyclone that descended from Canada upon the Great Plains States on the 11th, swept down to the Gulf of Mexico by the morning of the 12th, and recurved thence to the northeastward on succeeding days. The development of a cyclone over southeastern Georgia is the second

FIGURE 27.—WEATHER CHART OF FEBRUARY 10, 1899

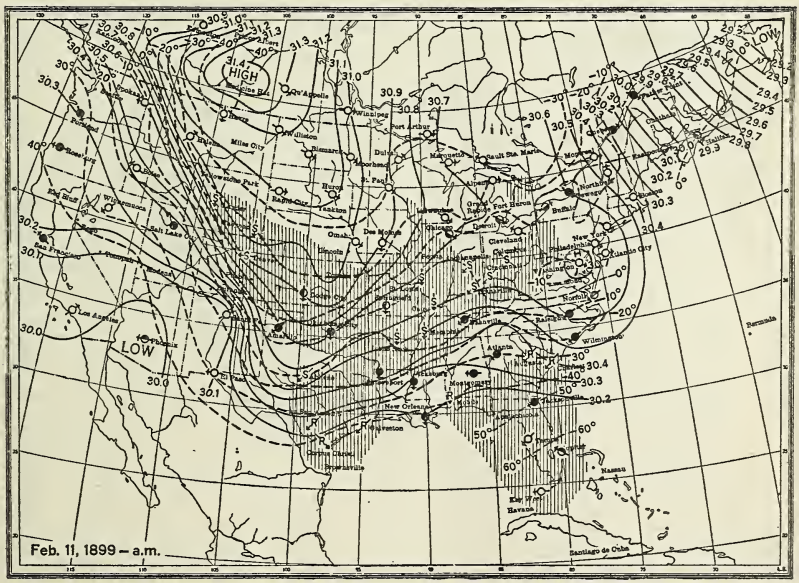

FIGURE 28.—WEATHER CHART OF FEBRUARY 11, 1899

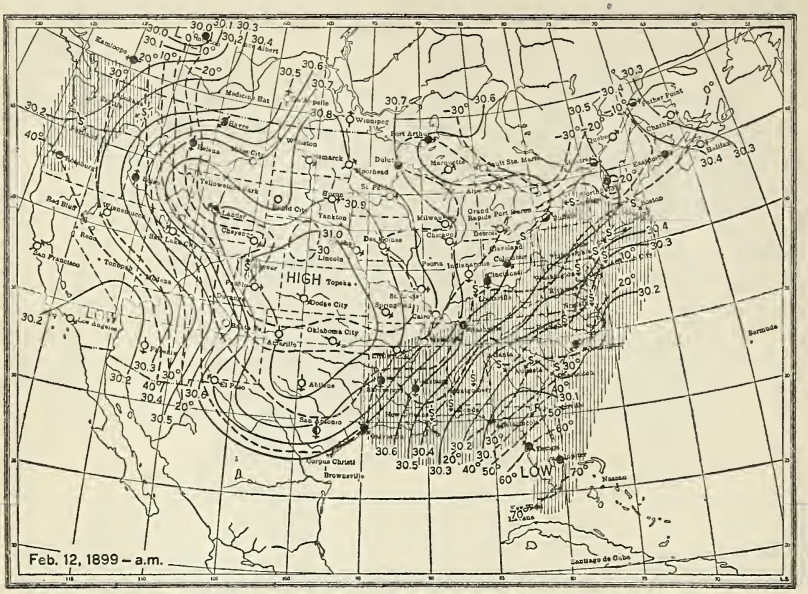

FIGURE 29.—WEATHER CHART OF FEBRUARY 12, 1899

FIGURE 30.—WEATHER CHART OF FEBRUARY 13, 1899

point of interest; this may be recognized from the inward loop in the isobar 30.2 inches where it passes over that State. That loop indicates a fall in pressure back from the coast over the interior, and the already-existing steep pressure gradient for northeast wind over the State furnishes the energy to start the whirling wind system of a cyclone. The whirl will be complete as soon as the warmer ocean winds to the southeast side of Georgia enter into the circulation. This happened sometime during the night of the 12th. By the evening of that date the cyclone was off the New Jersey coast as a near blizzard, with hurricane wind velocity driving the snow as it fell. Traffic in New York Harbor came to a stand.

This series of charts typifies the conditions which cause very severe weather. The major air currents that entered the cyclonic storm of February 11–13 were of different temperature and moisture content, and the resulting weather closely approximated the limit of severity experienced along the northern Atlantic seaboard in the last fifty-odd years.

SLEET AND ICE STORMS

The barometric formations that give rise to sleet, snow, or rain, and ice storms are of much the same general type, a common characteristic being the close juxtaposition within or near them of air currents having widely different temperatures. The forecaster has no definite observational data as to either temperature or moisture in the free air and is left to draw such inferences as to these conditions as he can from surface observations.

Sleet may be defined as precipitation that occurs in the form of frozen pellets either of ice or loosely compacted snow. The latter is sometimes referred to as soft hail or the graupel of the Germans. Sleet of itself unless it accumulates to a depth of several inches on the ground is not a serious problem; when, however, it accumulates to depths of 4 to 6 inches it becomes a serious menace to all forms of land transportation. Ice, or to use the more recent term "glaze," storms are by far the most destructive form of precipitation that can be experienced by a community. The known facts in connection with these storms are: The temperature of the surface air and objects within it is considerably (8° to 10° F.) below freezing. Because precipitation is in liquid form the assumption is that a pronounced temperature inversion is present in the superincumbent air. How much the falling rain is cooled while passing through the surface layer of cold air is not known with certainty but it can not be large. The rain, as soon as it touches an object whose temperature is much below 32° F., immediately freezes as clear ice, and the continued precipitation soon forms an icy coating that accumulates so rapidly that its weight breaks twigs and even branches of trees from their trunks and crushes to earth miles of telegraph and telephone wires.

The forecasting of these storms is not at all satisfactory, since, as before stated, the forecaster knows nothing except by inference as to the physical changes that are taking place in the circulation of the storm and is generally unable to accurately define those areas where the precipitation will be in the liquid or solid form. At best there will be some uncertainty as to the boundaries of those regions where the precipitation will be liquid and those regions where it is liable to be in the frozen or solid form.

Frankenfield (*9, p. 259–260*), distinguishes the following-named meteorological conditions as favorable for the occurrence of sleet and ice storms:

(1) Low temperature and high pressure to the northward (between northwest and northeast).

(2) Steep pressure and temperature gradients to the northward (between northwest and northeast). . . .

(3) Surface temperatures below the freezing point, usually between 22° and 28°; that is to say, surface temperatures between 22° and 28° 24 to 36 hours later. In other words, with other conditions favorable for sleet formation it will be likely to occur where the temperatures 24 to 36 hours later will be from 22° to 28°. This involves an accurate temperature forecast. . . .

(4) Moderately high pressure and high temperatures over the east Gulf and South Atlantic States. . . .

(5) Northward looping of the isotherms (surface inversion).

(6) Gentle to fresh northerly winds, northwest to northeast, increasing by the time sleet begins. . . .

(7) Low-pressure trough trending southwest to northeast between two HIGHS. The LOW is usually moving from the southwest, but sometimes from the northwest.

This appears to be a general rule except over the districts from the Southwestern States northeastward through the Ohio Valley, where the trough was absent about as often as present.

MISCELLANEOUS FORECASTS

THE TEMPERATURE FORECASTS

The great majority of temperature changes from one day to the next are so small as to be of little significance, and no attempt is made to forecast them. In order to secure uniformity, a rule has been adopted which requires a forecast of temperature to be made whenever the forecaster expects a change either up or down of as much as 10°, or more, in the months December, January, February, and March; 8° in April, May, October, and November; 6° in June, July, and August.

A number of special temperature forecasts because of their application to economic problems are of much value and importance. The shippers' forecast, issued whenever necessary to protect perishable products from injurious temperatures is an example in point. The use of refrigerator cars—cars whose temperature is artificially controlled within certain limits—obviates the necessity of protection under well-known seasonal temperatures, but frequently shipments must be made in ordinary box cars in which case a preknowledge of the temperatures likely to be encountered in the journey is quite helpful, as it is occasionally in the case of refrigerator-car shipments.

Perhaps, however, the temperature forecast of the greatest practical importance is the cold-wave warning, a special temperature forecast announcing a sudden drop in the temperature of 16°, 18°, or 20° or more to a minimum that is named in the warning. Warnings of killing frost are also issued, but these, so far as they apply to staple crops, are of less general application than the cold wave-warnings. The frost forecast is especially adapted to the needs of the truck and vegetable growers.

It would require more space than is available to go into the technic of making temperature forecasts of the several classes as above enumerated. Suffice it to say that they are based essentially upon the inherent characteristics of cyclones and anticyclones, their interrelations, speed of movement, etc.

COLD WAVES

As an example in weather chart reading for cold waves those for February 10-13, 1899, have been selected. (Figs. 27, 30, previously used to illustrate the heavy-snow forecast.) These charts portray the pressure distribution and movement during the occurrence of the lowest temperature of record in the Gulf States and Florida and a near blizzard in the Atlantic Coast States from the Carolinas to New England.

The outstanding feature of these charts is the presence of an anticyclone with central pressure of 31 inches and over in the Canadian Province of Alberta on the morning of February 10 and its subsequent movement southeastward to the Gulf of Mexico by the morning of February 12. (Figs. 27–30.) This movement seems to have been largely a gravitational flow of cold air down slope toward the Gulf. The barometric situation differed from the usual in the absence of a cyclone in front of the anticyclone whereby the flow of cold air from high to low latitudes is greatly facilitated. Pressure was low, to be sure, from New Mexico northward to Montana, there being a difference of an inch between the two regions.

The official forecasts of February 10, 11, and 13 are presented below.

Forecasts until 8 p. m. February 11, 1899

New England and eastern New York: Fair and continued cold to-night and Saturday.

District of Columbia, Delaware, Maryland, and Virginia: Fair and continued cold tonight; Saturday possibly snow and not so cold.

Eastern Pennsylvania and New Jersey: Fair and continued cold to-night; Saturday not so cold and fair, except possibly snow in extreme southern portion.

North Carolina: Cloudy with snow to-night and Saturday; not so cold Saturday.

South Carolina and Georgia: Snow in northern, rain in southern portions to-night; Saturday rain; not so cold in northern and western portions Saturday.

Eastern Florida: Rain to-night and probably Saturday.

Western Florida: Snow or rain to-night; Saturday rain and not so cold.

Alabama: Snow or rain to-night and probably Saturday; not so cold Saturday.

Mississippi: Snow in northern and rain or snow in southern portion to-night and probably Saturday; not so cold Saturday.

Louisiana: Snow in northwestern and rain in southeastern portion to-night; Saturday probably rain; not so cold in northwestern portion to-night; rising temperature Saturday.

Eastern Texas: Snow in northern and rain in southern portion to-night; Saturday rain; rising temperature.

Western Texas: Fair to-night and Saturday, except possibly snow in the Panhandle to-night; rising temperature.

New Mexico: Fair to-night and Saturday.

Oklahoma and Indian Territory: Fair and not so cold to-night and Saturday.

Arkansas: Snow to-night and probably Saturday.

Tennessee and Kentucky: Fair in eastern and snow and not so cold in western portion to-night; Saturday snow and not so cold.

West Virginia: Fair and not so cold to-night and Saturday.

Western New York: Fair and continued cold to-night and Saturday.

Western Pennsylvania: Fair to-night and not so cold in southern portion; Saturday fair and not so cold.

Ohio: Fair to-night and not so cold in central and extreme southeastern portion; Saturday probably snow in western and northern portions; not so cold.

Indiana: Fair to-night; Saturday snow in southwestern, fair in northeastern portion; not quite so cold to-night and Saturday.

Illinois: Snow to-night and Saturday; not quite so cold to-night.

Lower Michigan: Fair and not so cold to-night; Saturday fair.

Upper Michigan: Fair to-night and Saturday.

Wisconsin: Fair and not so cold to-night; Saturday snow.

Minnesota: Snow in southern, fair in northern portion to-night; Saturday fair.

Iowa: Snow to-night and Saturday; not so cold to-night in east portion.
Missouri: Snow to-night and Saturday; not so cold to-night.
North Dakota: Fair to-night and Saturday.
South Dakota: Fair to-night and Saturday; colder to-night in western and central portions; norther in southern portion.
Nebraska: Snow to-night; Saturday snow in southeastern, fair in northwestern portion; colder to-night in western portion; Saturday colder; norther.
Kansas: Snow to-night; Saturday snow and colder; norther.
Colorado: Snow and colder to-night and Saturday; norther; cold wave in northern portion.
Wyoming: Snow and colder to-night; Saturday fair, colder in southern portion.
Montana: Snow in southern, fair in northern portions to-night; Saturday fair; colder to-night.

Forecast till 8 p. m. February 12, 1899

Maine, New Hampshire, and Vermont: Fair; continued cold to-night and Sunday.
Massachusetts, Rhode Island, and Connecticut: Snow to-night and Sunday, preceded by fair on the coast; continued cold.
Eastern New York: Fair in northern, snow in southern portion to-night and Sunday; continued cold.
District of Columbia, Delaware, Maryland, and Virginia: Light snow to-night and probably Sunday; not so cold to-night.
Eastern Pennsylvania and New Jersey: Snow to-night and probably Sunday; not so cold to-night.
North Carolina: Snow in northern, rain in southern portion to-night and probably Sunday; not quite so cold to-night.
South Carolina: Rain in southern, rain or snow and warmer in northern portion to-night; Sunday rain.
Georgia: Rain to-night and Sunday, except possibly snow in extreme northeastern portion to-night.
Eastern Florida: Rain to-night; Sunday fair, except rain on Atlantic coast.
Western Florida: Rain and continued cold to-night and Sunday.
Alabama: Snow in northern, rain in southern portion to-night, except rain in extreme southern portion; continued cold.
Mississippi: Fair, except snow or rain in southern portion to-night and rain Sunday in extreme southern portion; continued cold.
Louisiana: Fair, continued cold to-night and Sunday, except rain to-night on the coast; continued cold.
Eastern Texas: Fair to-night except rain and colder on the coast; Sunday fair and continued cold.
Western Texas: Fair to-night; colder in extreme western portion; Sunday fair; continued cold.
New Mexico: Fair; colder to-night; Sunday fair, continued cold.
Oklahoma and Indian Territory: Fair; continued cold to-night and Sunday.
Arkansas: Fair to-night and Sunday; colder to-night in northwestern portion.
Tennessee and Kentucky: Fair to-night and Sunday, except snow to-night in eastern portion.
West Virginia: Snow to-night and probably Sunday; not so cold to-night in southeastern portion.
Western New York, western Pennsylvania, and Ohio: Snow to-night and probably Sunday; continued cold.
Indiana: Fair and colder to-night; Sunday fair.
Illinois: Fair, colder to-night in southern and eastern portions; Sunday fair.
Michigan, Wisconsin, Minnesota, Iowa, North and South Dakota, Nebraska, and Kansas: Fair to-night and Sunday.
Missouri: Fair to-night and Sunday; colder to-night in southeastern portion.
Colorado: Snow, colder to-night in extreme western portion; Sunday snow in southern, fair in northern portion.
Wyoming: Snow to-night in southern and central portions; Sunday fair.
Montana: Fair to-night; Sunday fair, probably not so cold.

February 12 being Sunday, no detailed forecasts were made.

Forecast until 8 p. m. February 14, 1899

Maine, New Hampshire, and Vermont: Snow this afternoon and to-night, probably heavy, followed Tuesday by fair in the interior; continued cold.

Massachusetts, Rhode Island, and Connecticut: Heavy snow this afternoon and to-night; Tuesday probably fair; continued cold.

Eastern New York: Heavy snow this afternoon, clearing to-night; Tuesday fair, high northerly winds.

Eastern Pennsylvania and New Jersey: Clearing this afternoon or to-night; Tuesday fair; colder to-night in southern portions.

District of Columbia, Delaware, Maryland, and Virginia: Clearing this afternoon or to-night, Tuesday fair; colder to-night.

North Carolina: Clearing this afternoon, fair to-night and Tuesday; continued cold.

South Carolina: Clearing this afternoon, fair to-night and Tuesday; continued cold, except not so cold Tuesday in western portion.

Georgia, Alabama, and western Florida: Fair, continued cold to-night; Tuesday fair; not so cold.

Eastern Florida: Fair, continued cold to-night; Tuesday fair with slowly rising temperature.

Mississippi: Fair, continued cold to-night; Tuesday fair; not so cold.

Louisiana: Fair to-night and Tuesday; not so cold to-night in western portion; rising temperature Tuesday.

Texas: Fair, not so cold to-night and Tuesday.

New Mexico: Fair to-night and Tuesday; warmer Tuesday.

Oklahoma, Indian Territory, and Arkansas: Fair, not so cold to-night and Tuesday.

Tennessee and Kentucky: Fair to-night and Tuesday; not so cold to-night in western portions; warmer Tuesday.

West Virginia: Fair, continued cold to-night; Tuesday fair, not so cold in northwestern portion.

Western Pennsylvania: Fair, continued cold to-night and Tuesday.

Western New York: Fair to-night and Tuesday, except snow flurries along the lakes to-night.

Ohio: Fair, continued cold to-night; Tuesday fair, not so cold in southwestern and western portions.

Indiana: Fair, with rising temperature in southwestern portion to-night; Tuesday fair with rising temperature.

Illinois, Wisconsin, Iowa, and Missouri: Fair, with rising temperature to-night and Tuesday.

Lower Michigan: Fair, with rising temperature to-night in western portion; Tuesday fair, rising temperature.

Upper Michigan: Snow flurries, with rising temperature to-night and Tuesday.

Minnesota: Fair, with rising temperature to-night; Tuesday fair, with rising temperature in extreme eastern portion.

North Dakota and South Dakota: Fair, with rising temperature in eastern portion to-night; Tuesday fair.

Nebraska: Fair, with rising temperature to-night; Tuesday fair.

Kansas: Fair, with rising temperature to-night; Tuesday fair, with rising temperature in eastern portion.

Colorado: Fair, with rising temperature in southeastern portion to-night; Tuesday fair.

Wyoming and Montana: Fair to-night and Tuesday.

Another striking feature of this series of charts was the development of a cyclone over southeastern Georgia on the night of February 12. The circulation thus developed caused warm oceanic air to flow inland, most likely in the higher levels over intensely cold surface air, thus causing general precipitation of moisture in the form of snow from the Carolinas northward.

One degree below zero was reached both at Vicksburg, Miss., and Mobile, Ala., the only case of zero temperature reaching so close to the Gulf of Mexico.

Another form of special temperature forecast is that known as the frost-fruit forecast, one that is made and distributed in the interest

of fruit growers in Washington, Oregon, Idaho, Utah, and Colorado, for cranberry growers in New England, New Jersey, Wisconsin, and Washington, and for the citrus growers in southern California. This forecast finds its fullest application in connection with the artificial heating of orchards and orange groves in the States named. Deciduous fruit growers heat in blossoming time, while the citrus grower heats to protect the maturing crop, and both are dependent on the Weather Bureau for special advices as to when to begin heating.

See categorical list of specialized temperature forecasts, page 10.

THE FOEHN OR CHINOOK

The well-known foehn wind of the Alps in Europe has its counterpart in the United States and Canada, where it has received the name "chinook." It may be defined as a dry, descending wind that is warmed by compression as it descends from higher to lower altitudes. The best examples of this wind are found when and where it descends from the summits of the Rocky Mountains to the plains to the eastward, and where the descent is most abrupt and greatest the warming is likewise greatest. Pueblo and Colorado Springs, Colo., are places where the warming effect of descending winds may be frequently observed in the cold season.

Any pressure distribution that will cause a flow of air across the mountains in either direction will result in warming by compression on the leeward side as low levels are reached.

THE TORNADO

The tornado is the most violent of all wind whirls. Its almost invariable characteristic is a funnel-shaped cloud that appears to hang from the bottom of a much greater cloud mass above. The wall of the funnel consists of a mass of violently whirling air with strong ascending components. The funnel itself may be 50 to a few hundred feet in diameter; the whole system, cloud, funnel, and its destructive winds, generally progresses in a narrow path (a few feet to a quarter of a mile in width) from southwest to northeast at a speed of 30 to 50 miles per hour. The length of the path varies from a few miles to 200 or more in extreme cases.

The tornado has three motions: (1) A progressive one from the southwest to the northeast, with an average speed of 30 to 50 miles per hour, (2) a violent updraught in the center of unknown velocity; and (3) the violent whirl around the vortex of the tornado that increases as it approaches the central core of low pressure. The average tornado path is from 100 yards to say three-eighths of a mile wide, and its length may vary from a few miles up to 200 or more. Tornadoes have a tendency to occur in groups of two, three, four, or more, each having a path parallel to that of what may be called the original tornadic storm.

The surface conditions that are favorable to the development of tornadic storms are as follows: The presence of a cyclonic depression in the southeast quadrant of which the morning temperature and humidity are rather high; the wind in the south or southwest; and an anticyclone with northerly winds located to the northwest of the cyclone. Humphreys (*10*) postulates the formation of a cold front or squall line in the free air a kilometer or so above the surface, and that

local convections develop along it here and there. But the occurrence of this phenomenon is not shown on synoptic charts. The details are too technical to be given in an elementary work such as this.

The Weather Bureau, realizing that it is unable to forecast when and where a tornado will strike, refrains from the attempt, and holds to the policy of silence with reference to them. Some years ago it was permissible to say in the official forecasts, "Conditions are favorable for the occurrence of destructive local storms," when in the judgment of the forecaster that fact was indicated on the weather chart. That policy was abandoned, however, on the ground that it created fear and unrest in the minds of a great number of persons, whereas if the storms did occur, only a comparatively few would be directly involved. Whether or not a policy of silence is the best method is, in the minds of some, still a debatable question. Weather Bureau forecasters are permitted to say "Conditions are favorable for the occurrence of severe thunderstorms or severe local storms" when such is the case.

TROPICAL CYCLONES

Tropical cyclones are known under several names. In the West Indies and Caribbean region they are called "West Indian hurricanes," in tropical regions of the western Pacific the name "typhoon" is applied to them, while in the eastern part of the north Pacific off the west coast of Central America the term "hurricane" following the practice with respect to the storms of the West Indies seems to have the preference. In all, there are six regions in the tropical parts of the great oceans where tropical cyclones originate. These are the north Atlantic from the Cape Verde Islands west to the Caribbean and Gulf of Mexico; (2) the north Indian Ocean on either side of India; (3) the south Indian Ocean to the east of Madagascar, near Mauritius; (4) the south Indian Ocean, between the northwest coast of Australia and the Cocos or Keeling group of islands; (5) the north Pacific, over the China Sea and eastward across the Philippines to about the one hundred and fortieth meridian east longitude; (6) the south Pacific from the Queensland coast eastward to about the one hundred and fortieth meridian of east longitude.

These storms develop mostly in the warm season, in the West Indies from August to October, although they may develop in both June and July. In the western Pacific the season for typhoons is longer, viz, from May to November. The season of intense cyclones in the Bay of Bengal extends from April to December, with maximums in May and November (*12, p. 273*). In the Arabian Sea the season is from June to November.

At this season of the year there are large areas of light winds, and sultry and rainy weather in that part of the tropical seas known as the doldrums. The general drift of the air in those regions is toward the west, and naturally tropical cyclones originating therein are carried westward along the southern border of the summer anticyclones found between 30° and 35° north latitude, in the Northern Hemisphere.

Since the tendency of all cyclonic storms is eventually poleward, tropical cyclones tend to recurve to the northeast in the Northern Hemisphere as soon as a pressure distribution favorable thereto is reached. In the Southern Hemisphere the recurve is toward the

southeast. After passing into higher latitudes they lose their tropical characteristics.

Tropical cyclones differ from those of extratropical latitudes in the following essentials: (1) They are much more intense and cover a smaller area, the most intense ones having a diameter on the average of 300 to 400 miles, as against a diameter of 1,000 miles in occasional extratropical cyclones; (2) they evidently extend upward in the atmosphere to a height of at least 5 miles, as evidenced by the movement of high clouds; (3) the barometer sinks to a lower level in the tropical than in extratropical cyclones, and the winds are much more destructive in the former than in the latter; (4) tropical cyclones are not associated with anticyclones in the same sense as in the extratropics; (5) there is in the tropical cyclone a central area of calm known as the eye of the storm, having a diameter of 10 to 15 miles; and (6) tropical cyclones occur only in the warm season, whereas extratropical cyclones occur in the greatest number in the cold season.

Not all of the tropical cyclones that enter the United States from the West Indian waters endure long enough to pass into the easterly circulation of mid latitudes. A number of them apparently exhaust their energy over the Gulf States in great downpours of rain;[6] others have endured for 24 hours or more, but not as intense cyclones, although occasionally one moves northward over the States of the Atlantic seaboard as a rather violent storm of wind, if not of heavy rain. Such a one was that of September 27–30, 1896.

On the morning of September 27, 1896, a trough of low pressure stretched from the lower Lakes to the Gulf of Mexico. This trough was flanked on both sides by anticyclones of considerable magnitude, the western one having central pressure as great as 30.48 inches and the eastern or oceanic one having a pressure of 30.3 inches at Halifax, Nova Scotia. At this time the pressure in Florida ranged from 30.08 inches in the north to 29.9 inches at Key West. Twenty-four hours later the Key West pressure had fallen but 0.02 inch and the wind remained light.

In Figure 31 is shown the pressure distribution on the morning of September 29, on which date an elongated area of low pressure stretched from the Ohio Valley southward to Florida, the lowest pressure being 29.64 inches at Jacksonville, Fla. Without any previous history of the storm no one would for a moment suppose that a tropical cyclone was present on the morning of the 29th. The surface conditions were directly opposed to such a presumption. Mitchell has been able to trace this cyclone back to Guadeloupe on September 22. The center of the cyclone, however, never came within close enough range of an observing station to give an indication of its real intensity. Special observations at 1 p. m. of the 29th showed the center to be at Augusta, Ga., with lowest pressure 29.48 inches and still no wind velocities to speak of. Seven hours later the situation had changed. The center of the cyclone was then in southern Virginia, with lowest pressure, 29.3 inches, at Lynchburg, Va. Wind velocity at that station was but 16 miles per hour, and heavy rain was falling. At this time there were two centers, the first as just described

[6] The question has been asked "How can they exhaust their energy in downpours of rain?" When all of the powder in a skyrocket is burned the rocket ceases to function. By the same token when all of the water vapor in the air in the center of a tropical cyclone is condensed and no increment of moist air is brought in from the outside, the cyclone can not do otherwise than vanish.

and the second, that of an independent storm, that was moving eastward over the western part of Lake Erie, pressure 29.4 inches. The winds along the Atlantic coast between the Virginia Capes and Nova Scotia where the gradient was steepest, did not exceed 40 miles per hour. Between 11 p. m. and midnight the cyclone center passed over Washington, D. C., with a pressure of 29.12 inches and a recorded wind velocity of 70 miles per hour. Several lives were lost in near-by Virginia and Maryland, and damage to property aggregating a million dollars was wrought in the short space of half an hour.

The greatest violence was exhibited during the early hours of the 29th in Florida and again in Virginia beginning about 11 p. m. After midnight of the 29th the violence diminished, only to be renewed early the morning following in Cayuga and Cortland Counties, N. Y.

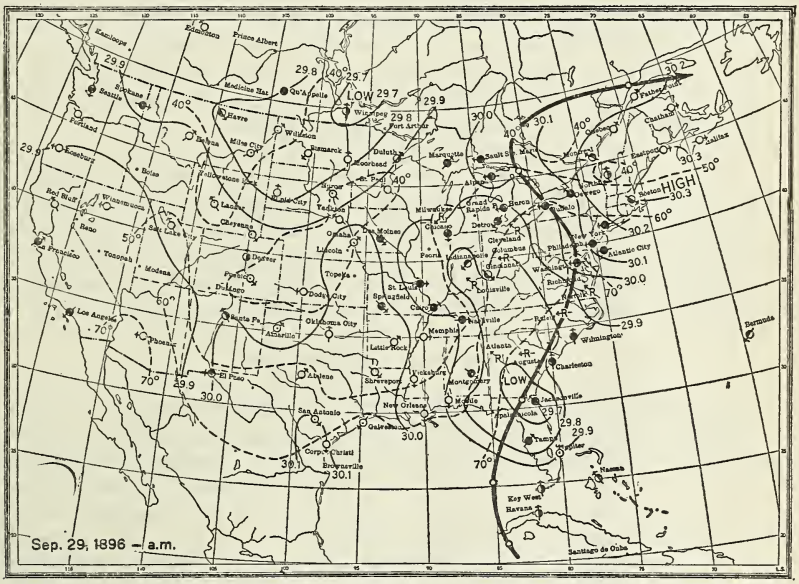

FIGURE 31

The westing made by this storm as it moved into higher latitudes seems to have been due to the existing pressure distribution. A somewhat similar track was pursued by the tropical cyclone of September 12–20, 1928, except that the latter, after following the coast of Georgia and South Carolina, swerved almost due north from Wilmington, N. C. This storm, too, passed into the path of an extratropical cyclone that was moving eastward over Ontario. And it also had a period of great violence, viz, from the morning of September 12 till the evening of September 16, as it moved inland over Florida. Its violence greatly diminished thereafter.

FOG

Until recently, the presence or absence of fog, except in the harbors of great cities on the Atlantic seaboard, was not a matter of sufficient importance to warrant the attempt to forecast it. On the Pacific coast, fog is a part of the daily régime of the weather, and is regularly

forecast. With the growth of aviation, however, the presence of fog is a distinct menace to the safe navigation of the air. The aviator is concerned not only with future weather, but also with present weather over the route he intends to travel. Synoptic charts based upon a rather wide network of observing stations can not be expected to show the occurrence of local fog or cloud at places not occupied by meteorological observers, and thus the original concept of a forecast service for aviation must be modified so as to provide for weather reports, not only at fixed hours, but practically continuously during flying hours. When the observing stations along any air route are placed at such small intervals apart as to give a continuous view of the weather and its changes from hour to hour, the service becomes one of reporting actual conditions existing at the moment rather than of forecasting future conditions.

Humphreys (*11*, p. *273–274*) classes fog as (1) radiation, and (2) advection. The first is due to the cooling of the surface of the earth during the night by radiation to the clear sky, and the second is formed whenever warm, humid air drifts over a cold surface, or the reverse, as when cold air flows over warm, humid regions.

A sharp distinction between fog and cloud can not be made, but since fog is a cloud on land, and cloud is a fog in the sky, perhaps a further distinction is unnecessary. In cyclones, the cloud level descends considerably, so that mountains and even high hills become cloud capped, while the valley below is clear up to an altitude of 500 to 1,000 feet. The height of the cloud ceiling in front of cyclones will vary, however, with the cyclones. No general rules can be laid down.

SEASONAL FORECASTS

This subject is approached with great diffidence for many reasons: (1) Because the problem is really an international one of extreme complexity, and (2) because of the utter lack of comprehension of the subject on the part of many writers who unfortunately are more or less influential in shaping public opinion. If one accepts at face value the comments that appear from time to time in the public press, the conclusion seems unavoidable that seasonal forecasting is already in the offing and that its successful accomplishment is only a matter of a few years.

It is probably a fact that very few of those who write about seasonal forecasting have any clear idea of just what they mean by that expression. At the bottom of a scale of seasonal forecasts is a forecast stated in general terms wholly lacking in definite statements either as to time or place as to what the weather of the season in its totality will be. By courtesy such a statement may be classed as a "seasonal forecast." Then there are graduations ranging from a bald guess to one that has the outward evidence of having some sort of scientific foundation. At the top of the scale what might be called the ideal seasonal forecast should have a place. This forecast should specify for any given area, not only how much rain may be expected but the manner of its distribution, whether in flood-producing rains or in beneficial showers. In like manner it should specify whether destructive periods of intense heat or, on the other hand, subnormal temperatures will prevail, when, and where. The occurrence of destructive hailstorms should be forecast.

Many wonderful and useful discoveries have been made in the last quarter of a century, of which transmission of intelligence by radio stands out prominently. This discovery and its development have furnished a strong right arm for progress in matters meteorological, especially in the collection and distribution of meteorological observations from and to the remote corners of the earth.

A considerable portion of the unthinking public has the impression that seasonal forecasting may come as a startling discovery. This belief should be corrected. Seasonal forecasting is not a laboratory problem unless the atmosphere of the globe as a whole is to be taken in hand and carefully observed and patiently studied. That means, if it means anything, that the atmospheric conditions over the entire known and inhabited portions of the globe, as well as those over the unknown and uninhabited, including the remote corners and all of the Seven Seas, shall come under study and investigation. For a graphic description of the extremes that will be encountered one would do well to read Conrad's description of the weather encountered on a voyage in tropical waters found in his novel, The Typhoon, (*3*) and for the other extreme as to weather conditions in Antarctica read the journal of that intrepid English explorer Captain Scott as printed in Scott's Last Expedition, volume 1 (*13*).

Thus one may realize the magnitude of relating as a harmonious whole the weather in different parts of the globe and the difficulty of distinguishing between those factors that may be important or unimportant in producing the complex we call the weather.

There is another phase of the subject that is to be deprecated, viz, it has become fashionable in very recent years to hold out the very alluring bait of a possibility of solving the question of seasonal forecasting in connection with sundry geophysical explorations. It has already been said that the problem is an international one, one that in the natural order of events should be considered by the international meteorological committee in cooperation with the International Union of Geodesy and Geophysics.

There is such a thing as launching a program of investigation before the time for it is ripe. See the paragraphs on the International Polar Commission, touched upon later.

Curiously, many otherwise intelligent and well-informed persons occasionally break into print in reference to matters meteorological without the intellectual preparation that they would consider as essential for one who essays to write informingly on astronomy, chemistry, or what not. Thus it happens that an added burden is placed upon the professional meteorologist, in that he must devote a considerable part of his time to the correction of the false ideas thus circulated.

Even professional meteorologists themselves may fail to sense the true course to pursue, as illustrated in the following paragraphs, all of which emphasizes the necessity of maintaining a certain amount of skepticism so as to avoid haste in any great undertaking.

In 1875, a lieutenant in the Austrian Navy, Karl Weyprecht, proposed the establishment of a network of meteorological stations around the North Pole for a year's observations. Weyprecht, himself an Arctic explorer, first presented his ideas to a meeting of naturalists at Gratz, Austria. The idea bore fruit, and four years later at an international geographic congress held at Hamburg, in which

meteorologists participated, a plan of exploration and detailed observations in the Arctic was approved. After the observations had been concluded, they were printed and circulated among the nations cooperating in the plan, and the twenty-odd ponderous volumes containing the year's observations printed in extenso presumably are still standing on the library shelves of the great meteorological libraries of the world. This is said, not in condemnation of meteorological research in the Arctic but as illustrating the fact that even with the best intentions possible the wrong course may be charted.

It is now easy to see that the effort involved in the international polar year of observations, August, 1882–83, was staged more than 50 years too soon. There was left a gap between the polar stations and those of the middle latitudes entirely too wide to span by any sort of interpolation and thus the relation of polar weather to the weather of mid-latitudes failed of discovery. At present the meteorological frontier on the north, in North America at least, is shoved much farther toward the Arctic Circle than was the case 50 years ago. It may be interesting to know that while this publication was being written, Point Barrow, a station occupied during the polar year 1882–83, was opened as a station of the United States Weather Bureau, the reports to be transmitted by radio.

This experience merely illustrates the fact that while the chief object of the research may not be attained, yet some side issue will come out of it that is really worth while. The side issue in this case was the compilation under the direction of the meteorological council of the British Meteorological Office of a most complete and detailed series of daily weather charts for the north Atlantic for the 13 months August, 1882–August, 1883, corresponding to and using so far as practicable the polar observations. Sir Napier Shaw (*14, p. 160*), in commenting on these charts, says:

> I think I am expressing the experience of others as well as myself when I say that the publication of this most valuable series of charts has been destructive of any hope of simple rules for weather sequence or for the movement of high and low pressure areas. The atmosphere over the north Atlantic is shown to be throughout the year in a state of turmoil which defies simplicity of description, and it is clear that something more than a process of classification is required before the sequences will become amenable to formulated law.

Thus in a very circuitous way it has been finally and definitely established that the suggestion put forth in the eighties that the progression of cyclones and anticyclones across the Atlantic would be an aid to forecasts for western Europe for some days in advance falls by the wayside; and, more than that, it proves, if any proof were necessary, that the extension of the methods used in the daily weather forecasts to a month or a season is an entirely impracticable proposition.

The principles underlying seasonal forecasts and those upon which the day-to-day forecasts are made are radically different. The only official government seasonal forecasts now attempted are those of monsoon rainfall for India and the Island of Java, the first-named being made under the direction of the director of meteorological observatories for India and the last by the director of the Magnetic and Meteorological Observatory at Batavia, Java. Both of these countries are tropical, and the meteorological conditions are quite constant as compared with those of the Temperate Zones. The

methods there used have not been as yet successfully applied to temperate latitudes of the Northern Hemisphere.

Sir Gilbert Walker, who served as director of meteorological observatories of India from 1904 to 1924 and was largely responsible for the development of the formula for forecasting the intensity of monsoon rainfall, finds in his study of world weather that there are three great swayings or surgings, as follows:

> (1) The North Atlantic oscillation of pressure between the Azores or Vienna on one hand and Iceland or Greenland on the other; (2) the north Pacific oscillation between the high-pressure belt and the winter depression near the Aleutian Islands; and (3) the southern oscillation, mainly between the south Pacific and the land areas around the Indian Ocean.

The southern oscillation in the enumeration above is more far-reaching in its effects than either of the other two. And since the effect of an abnormal season is propagated slowly, it may not be felt at the other side of the earth until an interval of six months or more has elapsed.

Finally, what is the outlook? The writer does not in the least wish to decry properly coordinated research into the problem of seasonal weather forecasting, provided the goal toward which such research is directed shall be adequately set forth. As before intimated, he can not escape the impression that the majority of persons and institutions which urge the study of the problem do not share a common idea of just what the term "seasonal forecasting" connotes when expressed in a percentage of the accuracy that is expected to be realized. This, he thinks, is the crux of the situation; one person may consider that any percentage above 50 is better than a mere guess, while another may believe that an accuracy that will equal that attained in the day-to-day forecasts, roughly 85 per cent, would be satisfactory. Any one who will think the proposition through to a logical conclusion will realize that only the second of the two extremes just mentioned would be worth while.

At present the special needs of aviation will absorb any increased grants that may be made by governing bodies in support of meteorological services. What seems to be needed is a well-conceived plan toward a fixed goal in which all of the nations of the earth will have a share. Haste will not only be futile but also very costly in the end.

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